

**THE LATE QUATERNARY LANDSCAPE HISTORY OF THE  
MIDDLE RÍO NEGRO VALLEY, NORTHERN PATAGONIA, ARGENTINA:  
ITS IMPACT ON PRESERVATION OF THE ARCHAEOLOGICAL RECORD  
AND INFLUENCE ON LATE HOLOCENE HUMAN SETTLEMENT  
PATTERNS**

A Dissertation

by

HEIDI MARIE LUCHSINGER

Submitted to the Office of Graduate Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2006

Major Subject: Anthropology

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Approved by:

Chair of Committee,	Michael Waters
Committee Members,	Vaughn Bryant
	Gustavo Politis
	Anne Chin
Head of Department,	David Carlson

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## **ABSTRACT**

The Late Quaternary Landscape History of the Middle Río Negro Valley, Northern Patagonia, Argentina: Its Impact on Preservation of the Archaeological Record and Influence on Late Holocene Human Settlement Patterns. (August 2006)

Heidi Marie Luchsinger, B.A., Barnard College; M.A., Texas A&M University

Chair of Advisory Committee: Dr. Michael R. Waters

Geoarchaeological investigations were conducted in the Middle Río Negro Valley in the northern portion of Patagonia, Argentina from 2004-2005. This project worked in conjunction with archaeological investigations in this region conducted by Lic. Luciano Prates (Universidad Nacional de La Plata, Argentina). No previous studies on the detailed reconstruction of the landscape history had been conducted in this valley. In order to place the archaeological record in this landscape context, this project had four main research objectives: 1) to reconstruct the landscape history; 2) to incorporate the known archaeological record into this landscape history; 3) to interpret natural formation processes and evaluate the preservation potential for archaeological sites; and 4) to interpret how landscape history could have influenced settlement patterns. Altogether, six months of fieldwork consisted of field reconnaissance of the landscape and recording of the regional stratigraphy through detailed analysis of sediments and soils, geomorphological features, and archaeological sites. This fieldwork was combined with analysis of aerial photographs, topographical and geological maps, and sedimentological

samples, in addition to the incorporation of radiocarbon and optically stimulated luminescence dating of stratigraphic units. As a result, through landscape reconstruction, it was possible to evaluate the preservation of the archaeological record, its landscape context, and to construct a predictive model for the location of archaeological sites from the Late Pleistocene through Late Holocene. Study of Late Holocene channel avulsion and the formation of pools within abandoned avulsion channels which occurred in one part of the study area suggest that landscape change potentially influenced Late Holocene settlement patterns in the Middle Río Negro Valley.

## DEDICATION

*In memory of*

*Dr. Robson Bonnichsen  
(1940-2004)*

*Dr. Richard Drees  
(1941-2005)*

*My deepest thanks to both for their influence on my development as an archaeologist.*

*I regret not having the opportunity to share this research with you.*

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of the stories from the field. Thanks to my friends and colleagues at the Universidad Nacional de La Plata: Mariano Bonomo, Patricia Madrid, Alejandra Matarrese, Agustina Massigoge, and Catriel Leon.

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## TABLE OF CONTENTS

	Page
ABSTRACT .....	iii
DEDICATION .....	v
ACKNOWLEDGEMENTS .....	vi
TABLE OF CONTENTS .....	viii
LIST OF TABLES .....	xi
LIST OF FIGURES.....	xii
 CHAPTER	
I      INTRODUCTION.....	1
II     SETTING AND ARCHAEOLOGY .....	4
Physiogeographic Setting.....	4
The Río Negro-Limay-Neuquén Drainage Network.....	4
Modern Environment and Soils of the Río Negro Valley .....	13
Paleoenvironment of Patagonia and the Pampas.....	15
Flooding and Modern Regulation of the Negro, Limay, and Neuquén Rivers .....	18
Modern Flooding History .....	19
Dam Construction and River Regulation .....	21
Archaeology of the Southern Pampas and Northern Patagonia .....	24
Initial Colonization of the Pampas (12,240-10,000 RCYBP)....	24
Summary of the Peopling of the Pampas .....	28
Early Holocene Population Increase, Survival of Extinct Megafauna, and Exploitation of Marine Resources .....	31
Middle Holocene Climate Change and Regional Specialization .....	31
Diversification and Intensification in the Late Holocene.....	33
Recent Investigations of the Pampean Coast and Northern Patagonia .....	35
III    METHODOLOGY .....	37
Introduction .....	37
Reconnaissance Methods .....	39

CHAPTER	Page
Field Recording and Data Collection .....	42
Recording Sediments and Soils.....	42
Recording Geomorphological Features of the Modern Surface .....	45
Recording Archaeological Sites .....	47
IV    LANDSCAPE HISTORY .....	49
Regional Pre-Quaternary Geological History .....	49
Regional Quaternary Geological History .....	52
Late Quaternary Geology of the Middle Río Negro Valley .....	53
Late Holocene Landscape History .....	69
Definition of Channel Avulsion .....	69
Pre-Conditions for Avulsion .....	74
Triggers of Avulsion .....	77
Channel Avulsion in the Middle Río Negro Valley .....	79
Stratigraphy and Dating of Avulsion Channels 1-3 .....	80
Chronology of Avulsion Channel 1 .....	83
Chronology of Avulsion Channel 2 .....	83
Chronology of Avulsion Channel 3 .....	84
Chronology of the Three Avulsion Channels.....	84
Geoarchaeology of the Avulsion Channels.....	88
Pools of the Three Avulsion Channels.....	88
Pool Types.....	94
Pool Formation.....	96
Role of Flooding in Formation of Avulsion Channel Pools.....	101
Summary .....	102
V    CONNECTING THE LANDSCAPE HISTORY WITH THE ARCHAEOLOGICAL RECORD: PRESERVATION OF THE ARCHAEOLOGICAL RECORD AND THE IMPACT OF LATE HOLOCENE LANDSCAPE PROCESSES ON SETTLEMENT PATTERNS .....	104
Introduction .....	104
Preservation of the Archaeological Record.....	105
Potential Impact of Channel Avulsion and Pool Formation on Late Holocene Settlement Patterns .....	110
VI    CONCLUSIONS .....	116

	Page
REFERENCES CITED .....	119
VITA .....	131



## LIST OF TABLES

TABLE	Page
1 Channel Dimensions Along the Río Negro (West to East) (after Soldano 1947).....	8
2 Channel Sinuosity and Slope Along the Río Negro (after Soldano 1947).....	8
3 Average Depth, Velocity, and General Channel Characteristics Along the Río Negro (West to East) (after Soldano 1947) .....	12
4 Average Depth and Velocity Along the Length of the Río Negro (West to East) (after Soldano 1947) .....	12
5 Dams and Dikes on the Río Limay and Río Neuquén .....	23
6 Radiocarbon Samples from the Arroyo Seco Site from the Lowest Level .....	26
7 Radiocarbon Samples from the Paso Otero 5 Site .....	26
8 Radiocarbon Samples from Various Archaeological Sites in the Tandilia Mountains.....	27
9 Miocene-Holocene Geology .....	50
10 Sedimentology of Fluvial Sand Overlying the Sandy Gravel at Location 1 and Location 2.....	68
11 Sedimentology of Eolian Loess Overlying the Sandy Gravel at Location 1 and Location 2.....	68
12 Radiocarbon Ages from the Middle Río Negro Valley.....	81
13 Pools Recorded in Each Avulsion Channel.....	91

## LIST OF FIGURES

FIGURE	Page
1 Study region in the Río Negro Valley .....	1
2 Arid steppe environment of the Middle Río Negro Valley .....	2
3 The Río Negro-Limay-Neuquén drainage network .....	4
4 a) Upper valley of the Río Limay looking upstream a few kilometers from its origin at the edge of Lago Nahuel Huapi; b) Glacial lake Lago Nahuel Huapi in mid-summer (early January). An ice cap remains on a mountain peak in center of the photo beyond the glacially carved U-shaped valley. ....	5
5 The upper valley of the Río Negro showing the tributaries that flow into the Río Limay and Río Neuquén (based on the map in Soldano 1947 prior to river regulation) .....	6
6 Middle valley of the Río Neuquén upstream from the Cerros Colorados reservoir. ....	7
7 Map of gauging stations locations along the Río Negro .....	9
8 Examples a) and b) of the variety in sinuosity of channel pattern found within the Río Negro River valley .....	10
9 Northern valley boundary of the incised Patagonian plateau. Gravel road is descending southwards (left of photo) from the plateau boundary into the Middle Río Negro valley.....	11
10 Downtown Viedma. Prates is pointing to a plaque indicating the water level during the flood of 1899 .....	20
11 Locations of river dams along the Río Limay and Río Neuquén.....	22
12 Archaeological sites mentioned in the text .....	25
13 Outcrops of the Río Negro Formation (blue sandstone) found within the Middle Río Negro Valley. Locations a) and b) are ca. 70 km apart ..	51

FIGURE	Page
14	Alluvial terrace ( $T_1$ ) incised by the modern channel. Undercutting by the river exposes the fluvial gravels seen spilling out of the profile (lower portion of the photo) ..... 54
15	a) Eolian blowout zone on surface of eolian mantle between avulsion channels 1 and 3 and b) sand dune complex (center of horizon) located between avulsion channels 1 and 2..... 54
16	Geomorphic map of the Middle Río Negro Valley. Pleistocene alluvial terraces are in the western portion ( $T_3$ and $T_2$ ) and the Holocene alluvial terraces ( $T_1$ and $T_0$ ) lie to the east of these deposits. ... 56
17	Generalized cross section of the Middle Río Negro Valley where Pleistocene alluvial terraces are preserved..... 57
18	View of Pleistocene terraces looking cross-valley from the southern edge of the valley where road cuts across Late Pleistocene terraces nearly perpendicularly ..... 58
19	Both a) at S 39° 41.255,' W 65° 45.676' and b) at S 39° 26.625', W 65° 46.541' are profiles of the Pleistocene gravel terraces and illustrate the degree of calcium carbonate accumulation and cementation in these terraces..... 59
20	Stratigraphy of Pleistocene Paleosol 2 underlying eolian deposition (S 39° 52.062, W 65° 26.277) ..... 60
21	Early to Middle Holocene fine gravel terrace (S 39° 39.321', W 65° 29.261'). a) Gravels extend down to shovel (center) but also deeper to bedrock; b) stratigraphy of fine gravel terrace ..... 61
22	Profile of the Early-Middle Holocene gravel terrace (S 39° 46.529', W 65° 24.558'). Dark sediment is coarse sand which is mixed with fine gravels with a very thin layer of eolian sediment (2-3 cm) preserved at the top of the profile..... 62
23	Clear erosional contact between the gravel terrace and overlying loess sediments ..... 63

FIGURE	Page
24	a) Gully cutting perpendicular to an abandoned channel of the Río Negro (S 39° 48.197, W 64° 56.222). Profile in Figure 20 was taken from the exposure on the left side of the photo where the tape measure is placed in the lower pit. b) Stratigraphic profile at Location 1. Unit 2 is designated the Rafael Paleosol. Note location of two OSL samples currently in process for dating the initial deposition of these units.....
25	a) Location 2 where fluvial sand was found preserved overlying sandy gravel deposit and b) sandy gravel unit (Unit 1) at base of profile .....
26	Stratigraphic profile of second location with fluvial sediment overlying sandy gravel deposit at Location 2.....
27	Location of the channel avulsions in the eastern portion of the study area (inside black box).....
28	Map of the three avulsion channels in the eastern portion of the study region .....
29	Avulsion Channel 2. Truck is located in the center of the channel bed which has been infilled with eolian sediments since abandonment ...
30	Avulsion Channel 1 as it appears in the landscape .....
31	Generalized stratigraphic cross section of the Middle Río Negro Valley showing the three avulsion channels .....
32	Composite section of Early-Mid Holocene fluvial sediments and locations of OSL samples currently in process .....
33	Profiles along Avulsion Channel 2 where radiocarbon samples were collected and dated .....
34	Composite section of the stratigraphy representing alluvial and eolian deposits along Avulsion Channel 2 .....
35	Profile of alluvium deposited by Paleochannel 3 at WP 356 (S39 56.365 W64 45.612) .....
36	Generalized stratigraphic cross section of the Middle Río Negro Valley .....

FIGURE	Page
37	Crescent-shaped pool located within a meander of Avulsion Channel 2 (flamingos in the foreground for scale) ..... 89
38	Dry pool inside Avulsion Channel 2 ..... 90
39	Location of pools recorded along the three avulsion channels ..... 93
40	The white material dried on surface sediments of pool perimeter is salt deposits ..... 94
41	Probable sequence of channel avulsion, loess infilling, and pool formation by flood channels..... 97
42	General scheme of the formation of a meandering river channel which results in a pool-riffle sequence within the channel bed where the pools are located within the meander bend and the riffles are located between meander curves (after Knighton 1998, p. 218)..... 98
43	Graded gravel splay located near the distal end of a dry pool which formed in Avulsion Channel 1 (dry pool in background at light area)..... 99
44	Fluvial gravels found on the dry channel bed of Avulsion Channel 2 near the distal end of a dry pool ..... 99
45	a) Standard scheme for a pool-riffle sequence (after Knighton 1998, p. 218). and b) observed pattern of pool-gravel sequence in each avulsion channel where pools formed within meanders ..... 100
46	Flood channel (center) cutting across Early to Middle Holocene alluvium from old meanders of the modern river (lower left corner) to avulsion channel 2. Note flood channel following course of avulsion channel 2 (upper right corner). ..... 102
47	Geomorphic map of the Middle Río Negro Valley ..... 106
48	Sequence of eolian deposits overlying alluvium in the Middle Río Negro Valley from the Late Pleistocene (LP), Early Holocene (EH), Middle Holocene (MH), and Late Holocene (LH). Archaeological sites may potentially be found in any of these strata (black triangles).... 108

FIGURE	Page
49	Potential locations for buried archaeological sites (black and gray triangles). Gray triangles signify sites occupied after pool formation in abandoned avulsion channels ..... 112
50	Wet pools (a) and (b) recorded in January 2005 ..... 114

## CHAPTER I

### INTRODUCTION

Geoarchaeological investigation of the Middle Río Negro Valley, Argentina, was conducted along a 150 km segment of the modern valley, approximately 200 km inland from the coast (Figure 1). As evident from sharp valley boundaries, the river deeply cuts into the northern portion of the Patagonia plateau. Within the valley, the landscape



**Figure 1.** Study region in the Río Negro Valley.

mainly consists of vast abandoned alluvial terraces that are blanketed by eolian deposits and arid steppe (Figure 2). This project investigated the Late Quaternary geological history of the river valley in order to place the existing archaeological record

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This dissertation follows the style and format of *American Antiquity*.



**Figure 2.** Arid steppe environment of the Middle Río Negro Valley.

into its landscape context. From the beginning of fieldwork, it was clear that the landscape history was a complex sequence of events that were the result of various natural processes which are not always readily apparent.

This geoarchaeological study is the first detailed investigation of the geomorphology to be conducted in this valley. There were four main objectives for this study: 1) to reconstruct the landscape history; 2) to incorporate the known archaeological record into this landscape history; 3) to interpret natural formation processes and evaluate the preservation potential for archaeological sites; and 4) to interpret how landscape history could have influenced settlement patterns. As a result, it was possible to identify and date buried landscape surfaces and predict locations for archaeological sites from initial colonization through the Late Holocene. In addition, it was possible to evaluate preservation of the archaeological record, construct a preliminary model for



human settlement patterns during the Late Holocene, and evaluate the impact that landscape history had on prehistoric human behavior.

A discussion of the study region and regional archaeology is presented in Chapter II. Methodology used during fieldwork is outlined in Chapter III. In Chapter IV, background on the Pre-Quaternary geological history is presented as well as a detailed discussion of the landscape history of the Holocene in the Middle Río Negro Valley. Following this discussion (Chapter V), the preservation of the archaeological record is presented as well as the impact on settlement patterns as a result of Late Holocene river channel avulsions.

This project was undertaken as part of a larger collaborative investigation of the Middle Río Negro Valley with Lic. Luciano Prates of the Universidad Nacional de La Plata. Over the past couple of years, Prates has conducted archaeological survey and has excavated two archaeological sites in this region (Prates 2004). These two projects conducted on the geoarchaeology (Luchsinger) and the archaeology (Prates) of this study area will result in a more holistic and comprehensive understanding of the archaeological record of the Middle Río Negro Valley.

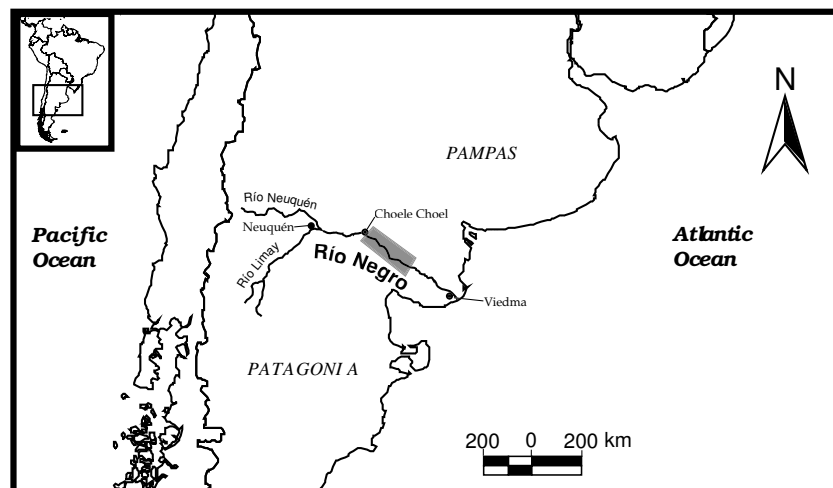
## CHAPTER II

### SETTING AND ARCHAEOLOGY

#### Physiogeographic Setting

##### *The Río Negro-Limay-Neuquén Drainage Network*

The Río Negro is not only the largest river in Patagonia, but it is also the largest river in southern South America. Formed by the confluence of the Río Limay and Río Neuquén, the Río Negro flows eastwards to the Atlantic coast for 728 km (Figure 3).

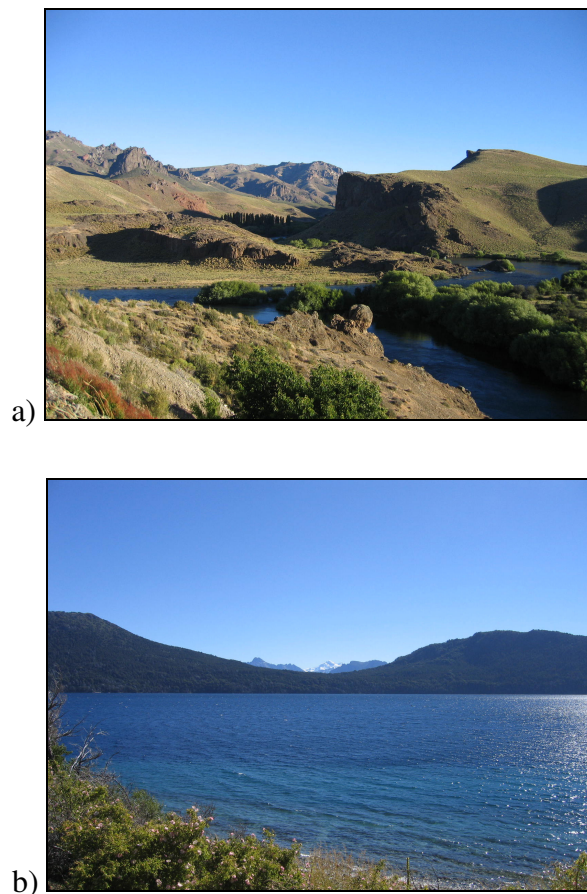


**Figure 3.** The Río Negro-Limay-Neuquén drainage network.

This fluvial network drains a 600 km segment of the Patagonian Andes between  $36^{\circ}15'$  S and  $41^{\circ}20'$  S, forming a drainage basin of  $65,000 \text{ km}^2$  (Soldano 1947). From the confluence of the Río Limay and Río Neuquén near the modern city of Neuquén (254.2

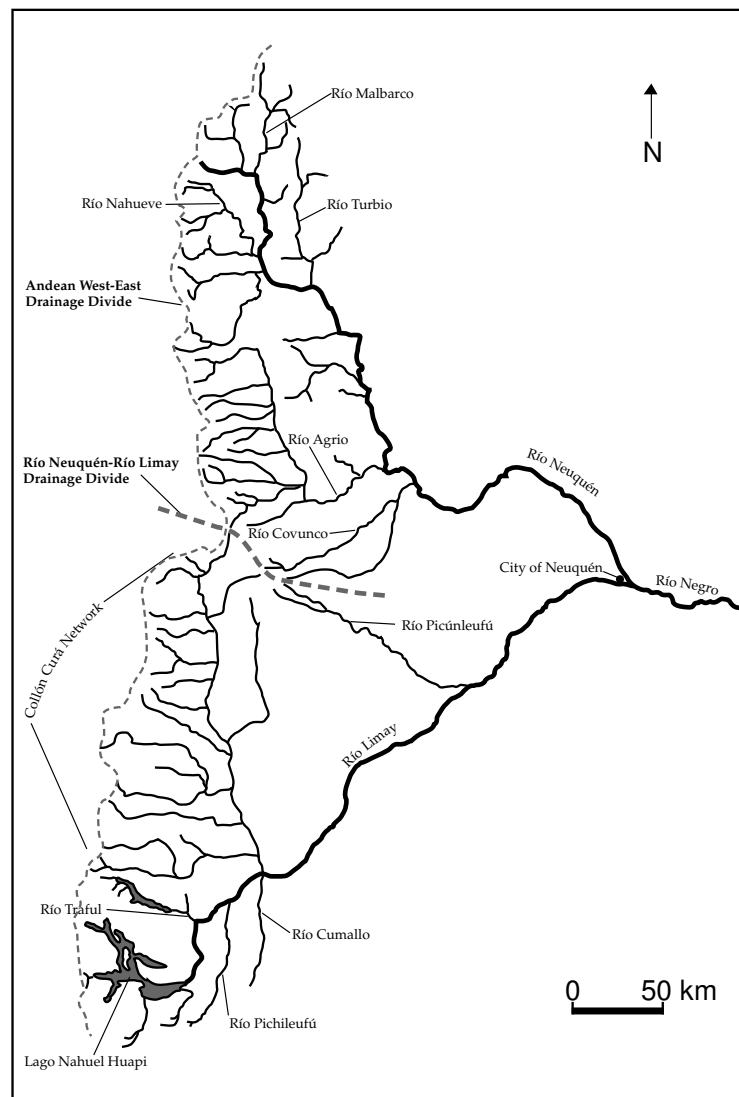
m.a.s.l.), the Río Negro flows east before curving slightly to the southeast near the town of Choele Choel and continues southeast until it empties into the Atlantic Ocean near the city of Viedma.

The Río Limay (Figure 4a) drains 23,500 km<sup>2</sup> and flows roughly northeast for 465 km before joining the Río Neuquén near the city of Neuquén (Soldano 1947). The source of the Río Limay is an alpine glacial lake, Lago Nahuel Huapi (Figure 4b),



**Figure 4.** a) Upper valley of the Río Limay looking upstream a few kilometers from its origin at the edge of Lago Nahuel Huapi; b) Glacial lake Lago Nahuel Huapi in mid-summer (early January). An ice cap remains on a mountain peak in center of the photo beyond the glacially carved U-shaped valley.

which is located 767 m.a.s.l. and has a surface area of 530 km<sup>2</sup>. Along the length of the Río Limay, 5 tributary systems join this river (the Traful, Pichileufú, Collón Curá, Cumallo, and Picúnleufú river systems), and altogether, these systems drain 37 glacial lakes and a total surface area of 1,149 km<sup>2</sup> (Figure 5).



**Figure 5.** The upper valley of the Río Negro showing the tributaries that flow into the Río Limay and Río Neuquén (based on the map in Soldano 1947 prior to river regulation).

The Río Neuquén (Figure 6) flows from the northwest towards its confluence with the Río Limay and drains 17,100 km<sup>2</sup>. In contrast to the Río Limay, although the headwaters for the Río Neuquén also originate in the mountains at 1800 m.a.s.l, this river only receives its discharge from tributaries and gullies rather than glacial lakes. This has a major impact on the stability of this fluvial regime as is discussed below. Crossing 493 km before joining the Río Limay near the city of Neuquén, 5 tributaries flow into the Río Neuquén: the Malbarco, Nahueve, Turbio, Agrio, and Covunco rivers (Figure 5).



**Figure 6.** Middle valley of the Río Neuquén upstream from the Cerros Colorados reservoir.

From the confluence, the Río Negro flows eastwards. The valley length from confluence to the coast is 535 km, although the actual channel course crosses 728 km (Soldano 1947). A summary of channel characteristics is found in Tables 1 and 2 and locations are found on the following map (Figure 7).

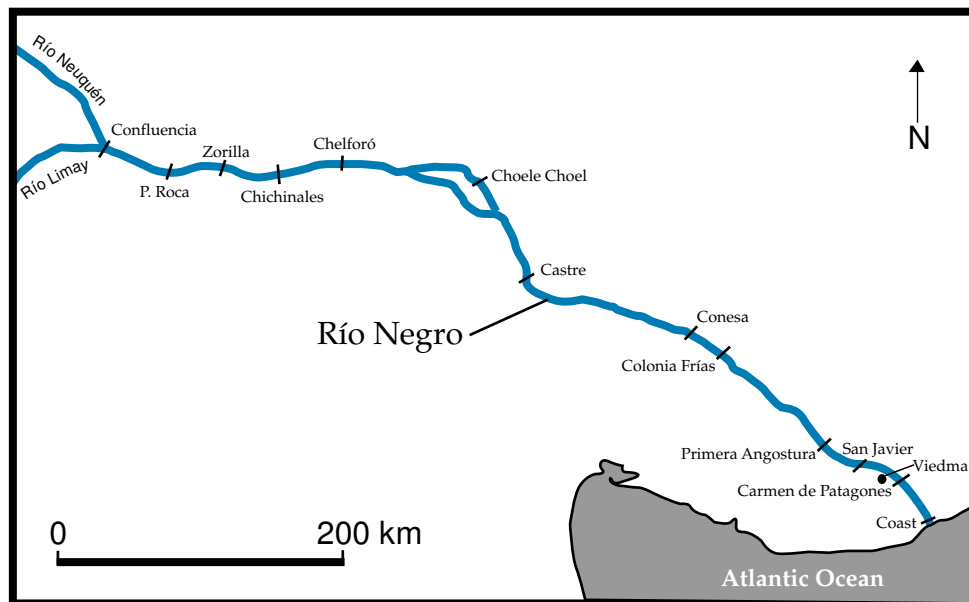
Table 1. Channel Dimensions Along the Río Negro (West to East) (after Soldano 1947).

Location	Distance (km) From Coast (along river course)	Distance (km) From Coast (along valley)	Channel Width (m)	Valley Width (km)
Confluencia	728	535	550	12.5
Est. aforos P. Roca	687	500	530	14.4
Zorrilla	630	456	550	8.1
Chichinales	602	436	450	8.3
Chelforó	565	402	450	4.4
Choele Choel	454	318	450	25
Castre	342	238	600	14.3
General Conesa	256	168	600	8.2
Colonia Frías	196	125	500	8.1
Primera Angostura	151	89	450	12
Carmen de Patagones	39	30	400	11.3
Coast	0	0	1000	12

Table 2. Channel Sinuosity and Slope Along the Río Negro (after Soldano 1947).

Location	Coefficient of Sinuosity*	Slope (m/km)
Confluencia-Est. aforos P. Roca	1.2	0.574
Est. aforos P. Roca-Zorrilla	1.3	0.514
Zorrilla-Chichinales	1.4	0.475
Chichinales-Chelforó	1.08	0.475
Chelforó-Choele Choel	1.62	0.41
Choele Choel-Castre	1.6	0.34
Castre-General Conesa	1.3	0.36
General Conesa-Colonia Frías	1.55	0.26
Colonia Frías-Primera Angostura	1.27	0.26
Primera Angostura-Carmen de Patagones	1.28	0.074
Carmen de Patagones - Coast	1.3	0.023

\*The Coefficient of Sinuosity is the Channel Length Divided by Straight-line Valley Length (Knighton 1998).

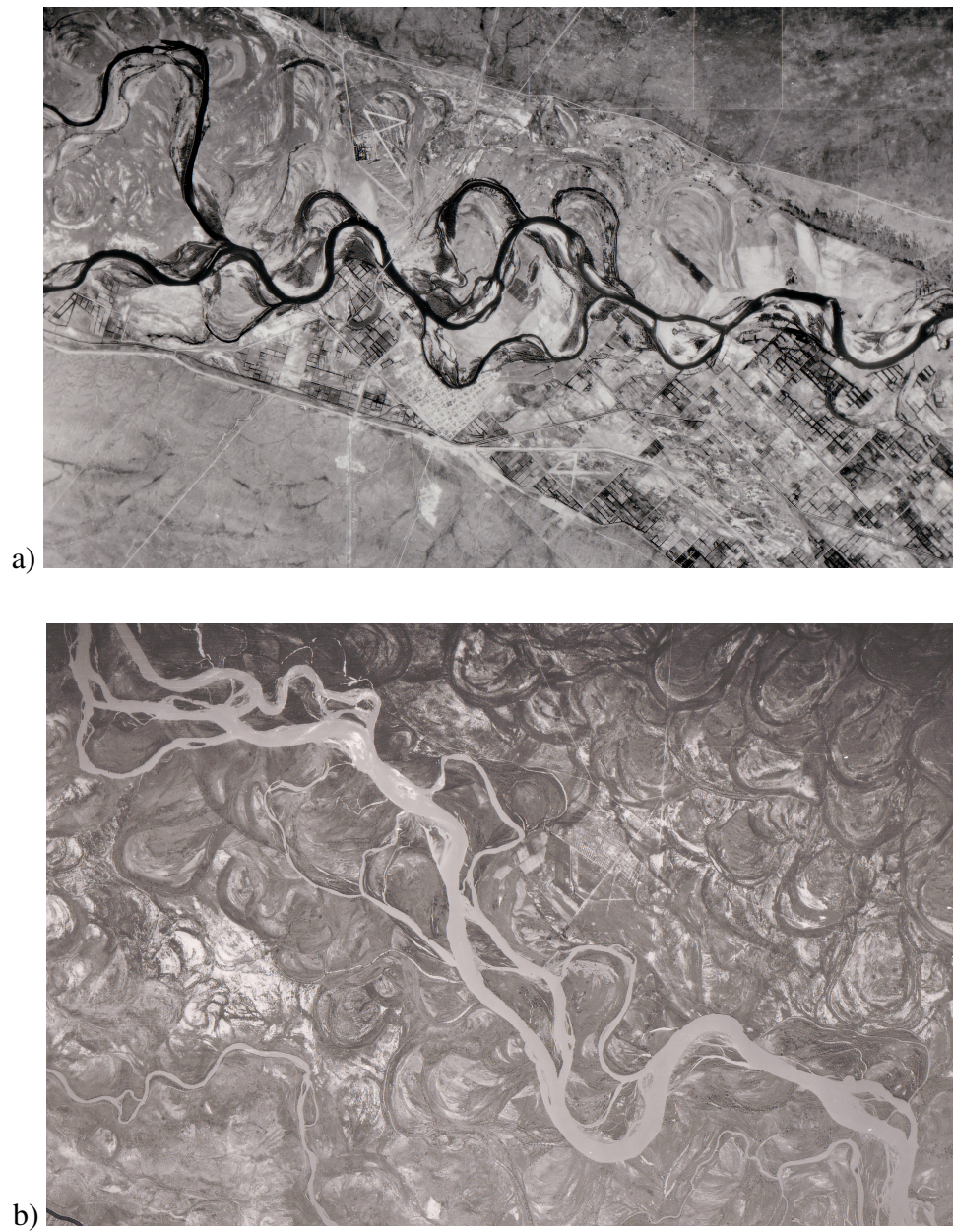


**Figure 7.** Map of gauging stations locations along the Río Negro.

Along its course, the Río Negro shifts between a meandering and anastomosing pattern. However, at times, the river channel exhibits characteristics of both patterns (Figure 8a and 8b). As a result, there are approximately 300 stabilized islands located within this river channel (Frangi and Malacalza 1978).

The Río Negro Valley varies from 5-25 km in width along its course and the widest part of the valley is near the town of Choele Choel (25 km). The surface area of the valley is 125,500 km<sup>2</sup> (Gudoy Manriquez 1997). The valley formed when the Río Negro deeply incised the northern Patagonia plateau (Figure 9). At the confluence of the Río Limay and Río Neuquén, the plateau is eroded to a depth of 200 m, its deepest point in the valley (Soldano 1947). Downstream from the confluence, the plateau and the surface of valley deposits differ between 25-50 m (Angulo, et al. 1979).





**Figure 8.** Examples (a) and (b) of the variety in sinuosity of channel pattern found within the middle Río Negro River valley.





**Figure 9.** Northern valley boundary of the incised Patagonian plateau. Gravel road is descending southwards (left of photo) from the plateau boundary into the Middle Río Negro valley.

The average width of the modern Río Negro river channel is 450 m. At its confluence, the slope of the Río Negro is 0.574 m/km. Near Choele Choel which is nearly the valley midpoint, channel slope is 0.41 m/km. Near the coast at the town of Carmen de Patagones, the slope decreases to 0.23 m/km (Soldano 1947). The average channel slope along its length is 0.35 m/km. Modern flow velocity averages between 5.28-8.39 km/hr, discharge varies between 1,000-4,000 m<sup>3</sup>/s, and channel depth of the Río Negro averages 2.66 m although it ranges from 0.55-10 m (Tables 3 and 4). From its confluence, no major tributaries flow into the Río Negro aside from intermittent gullies that line both sides of the valley. These gullies channel drainage from the plateau into the valley. Although this data stems from an older source (Soldano 1947), this river system does not appear to have changed significantly during the intervening years.

Table 3. Average Depth, Velocity, and General Channel Characteristics Along the Río Negro (West to East) (after Soldano 1947).

Segment	Depth (m)	Velocity (km/hr)	Misc.
Confluence-General Roca	0.75-5.5	up to 11	Large gravels in channel and variable velocity
General Roca-Chichinales	0.75-5.5	6-9	Wide curves and stable channel
Chichinales-Chelforó	0.55	9	Very narrow channels
Chelforó-Choele Choel	0.75-3.5	8	Very narrow channel
Choele Choel-Castre	0.75-5.75	4.6-8.5	Wide valley (25 km)and various brazos
Castre-General Conesa	0.75-5	4.7-8	Very sinuous and some rapids
General Conesa-Colonia Frías	0.7-5	4.5-8.5	Very sinuous and some rapids
Colonia Frías-Primera Angostura	1.0-5.0	5.7-6.5	Less sinuous
Primera Angostura-San Javier	4.2-8.5	0.75	Channel very sinuous and variable
San Javier-Coast	5.2-10	n/a	Tide influence (average 2.4 m at high tide)

Table 4. Average Depth and Velocity Along the Length of the Río Negro (West to East) (after Soldano 1947).

Location	Max. Depth (m)	Ave. Depth (m)	Min. Depth (m)	Ave. Velocity (km/hr)	Max. Velocity (km/hr)
Confluencia	5.25	2.4	0.75	6.5	9
General Roca	5.5	2.3	0.75	6.2	10.5
Chichinales	5.5	2.1	0.55	6.4	9
Chelforó	6.75	2.3	0.75	6.2	8.5
Choele Choel	5	2.6	0.75	4.7	7.5
Castro	5.5	2.6	0.75	4.4	8.5
Colonia Frías	5.5	3	1	3.8	6.5
Primera Angostura	6.75	2.9	0.75	5.1	8.5
San Javier	7	3.5	0.75	4.2	7.5
Patagones	10	5.2	2.4	n/a	n/a
Average	6.28	2.66	0.92	5.28	8.39

### ***Modern Environment and Soils of the Río Negro Valley***

The Río Negro Valley is an ecotone. It lies on the boundary between two large physiogeographic provinces, the Pampas and Patagonia. In turn, it shares many features in common with both provinces. The modern climate is arid to semiarid. At this latitude, the Andes impede humid Pacific winds from reaching this area, therefore, a rain shadow forms east of the Andes (Fidalgo and Rabassa 1984). In addition, this area is also outside the zone of Atlantic storms. As a result, the climate is arid, and dry winds blow predominantly from the west and southeast (Acevedo 1981).

In general, the vegetation of this region is classified as steppe vegetation and it is assigned to the plant-geographical province of monte of the Chaqueño dominion (Cabrera 1976). The annual precipitation of Northern Patagonia is 200 mm per year and this region consists of sparse vegetation of xerophytic shrub or barren desert (Clapperton 1993). With continual winds and low rainfall, the predominant vegetation consists of shrubs and grasses.

The climate in the Pampas is sub-humid to humid (Burgos and Vidal 1951). The average precipitation in the southern Pampas is 800 mm and temperature averages 14° C (Zárate, et al. 2000). The mean annual temperature is between 27° C (summer average) and 15° C (winter average) (Clapperton 1993). The physical geography of this region has a major impact on the climate of the Pampas in two ways. At approximately 40° S, there is a significant increase in land width and the Andes are approximately 50% higher at these latitudes than the mountains south of this latitude. As a result, cyclongenesis occurs when southwestern air from Patagonia meets polar maritime air from the South

Atlantic over the Pampas, creating weather systems that provide precipitation to the eastern Pampas. In the Pampas, the modern vegetation consists of grassland steppe (Cabrera 1968) with some patches of tropical scrub woodland (Caatinga, Chaco) (Clapperton 1993). The western portion of the Pampas is xerophytic shrub and barren desert, much like the rest of Patagonia.

Three circulatory systems influence the climate of Argentina, the Atlantic and Pacific subtropical high pressure cells, the Gran Chaco low pressure cell, and the mid-latitude westerlies (Prohaska 1976). One feature that is unique to Patagonia is the year-round presence of westerly winds which have a strong impact on the regional climate (Clapperton 1993). Strong westerly winds from the Pacific reach the western side of the Andes, compress as the air ascends, cross the mountain range and expand once they reach the eastern side, resulting in high pressure above the mountain range and low pressure on the eastern flank. This difference in pressure produces dry winds which are continually present across central Argentina. Therefore, the Andes in this region represent a clear boundary between climates on the Pacific and Atlantic sides of southern South America.

The majority of soils (62%) in the Río Negro province are Aridisols (Gudoy Manriquez 1997). Argides are found on the plains, plateaus, and in depressions for 7,838,331 hectares. In hilly areas, depressions, salty areas, and lakes, Ortides are common (ca. 4,559,154 hectares). Within the Río Negro Valley, Entisols are the most common. Ortentes are found on hillslopes, psamentes on accumulation plains, and fluventes and aquentes on the fluvial plains.

### ***Paleoenvironment of Patagonia and the Pampas***

In the Río Negro Valley region very few paleoclimatic studies have focused on this region although a few existing studies from Patagonia and the Pampas (Figure 3) are available to help reconstruct the general paleoenvironment of this valley. In Northern Patagonia, 17 lakes were cored for pollen and sedimentological analysis (Schäbitz 1994). Cores from two of these lakes, Salina Anzoátegui (39° 00'23" S, 63° 46'30" W) and Salina Piedra (40° 34'59" S, 62° 40'26" W), were studied in detail for reconstructing the Middle to Late Holocene. Results indicated that during the Middle Holocene, the climate was mainly arid but in the Late Holocene becoming more semiarid with a greater frequency of precipitation and more seasonability. Paleontological evidence from the Pampas (Figure 3) was also used to reconstruct paleoclimates from the Late Pleistocene through Holocene. These studies indicated that the climate during the Late Pleistocene and Late Holocene were arid with temperatures approximately 10° C less than today (Prado, et al. 1987; Tonni and Fidalgo 1978). In addition, during the Early Holocene, climate was more humid than previously while temperatures increased but stabilized during the Late Holocene when it became more arid.

Recent studies suggest that a majority of Late Quaternary eolian sediments were deposited during the Late Glacial Maximum (Krohling 1999; Zárate and Blasi 1991; Zárate and Fasano 1989). In contrast to the last glacial period, eolian deposition decreased dramatically by 11,000-10,000 BP (Muhs and Zárate 2001) although deposition increased for a period during the Middle to Late Holocene (Zárate and Blasi 1993; Zárate and Flegenheimer 1991). The Early to Middle Holocene period was more

humid in comparison to the Late Pleistocene and many sediments underwent pedogenesis. Modern soils form on stable surfaces consisting of Early Holocene loess or are cumelic forming on surfaces where eolian sediments are continuously deposited and incorporated into modern soils (Zárate, et al. 2000). Others believe that cold and dry conditions persisted until 8500 BP (Iriondo 1999; Tonni, et al. 1999). Grassland vegetation persisted in the central Pampas until 7800 BP and even into 5700 BP in southwestern Pampas (Prieto 1996). During the Middle Holocene between 5000-4000 BP, there appears to have been a significant increase in eolian deposition that continued into the Late Holocene and drier conditions that lasted until 1000 BP (Tonni 1992). At Bahía Blanca, sandy loess deposition began around 5200 BP (Gonzalez and Weiler 1987/1988) as well as in the Tandilia range (Zárate and Flegenheimer 1991). The same activity was recorded at several fluvial localities where sandy loess deposits between 1-2.5 m thick were found and had undergone some pedogenesis (Prieto 1996; Zárate, et al. 2000). In addition, there is evidence of soil truncation during this period along with desiccation of ponds and swamps where some soil formation occurred (Zárate, et al. 2000). The Late Holocene began by 1000 BP when there was a return to subhumid-semiarid conditions with psammophytic and halophytic plant communities (Prieto 1996), much like modern conditions.

In summary, most studies of the Pampean eolian record indicate that the last glacial period was cold and dry and possibly windy (Carignano 1999; Iriondo 1999; Krohling 1999; Krohling and Iriondo 1999; Zárate and Blasi 1993). It has been suggested that eolian activity was caused by drier climates when there was little

vegetation cover (Clapperton 1993). This period was followed by a more humid and warmer Early to Middle Holocene as indicated by an increase in soil formation and marked decrease in eolian deposition (Krohling 1999; Krohling and Iriondo 1999; Zárate and Flegenheimer 1991). During the Middle Holocene, there was a shift to slightly drier conditions (Iriondo 1999; Iriondo 1997; Krohling and Iriondo 1999; Zárate and Blasi 1993). Subhumid to semiarid conditions returned during the Late Holocene by 1000 BP (Prieto 1996).

Several paleoenvironmental studies have been conducted in Patagonia. The study conducted at Lago Masecardi in west-central Argentina was based on a sediment core taken from this proglacial lake fed by the meltwaters of the Tronador ice-cap (Ariztegui, et al. 1997). One core (core PMAS93.4) contained a record spanning the last 15,000 years. Ten radiocarbon ages were obtained from core PMAS93.4 spanning from 15,300-2500 BP from samples of subaquatic moss, bulk organic silt, and terrestrial macrofossils. An additional 15 radiocarbon ages from this core were reported on bulk sediment samples (Hajdas, et al. 2003). The Lago Masecardi record contains multi-proxy evidence for climate change of grain size, Hydrogen Index (HI), and pollen. During the period from 11,400-10,200 BP, this record indicates a significant decrease in sediment grain size, HI, and influx of pollen taxa. The decrease in grain size is characteristic of the fine-grained sediment deposited from a glacial advance. The decrease in HI values further indicates changes in the source and environmental conditions of deposition. Finally, this period experienced a decrease in *Nothofagus*, disappearance of *Chironomus*

sp. and *Sergentia/Lenzia*, which was accompanied by an increase of *Misodendrum* and *Podocarpus*.

Studies at Laguna Cari Laufquen in the Río Negro Province (41.13 S, 69.42 W, 800m) also provide indicators for past climate change (Galloway, et al. 1988). Lake levels appear to have been high during the late glacial period (18,400-13,000 BP) and significantly lower during the Holocene. Lake levels also rose significantly around 10,000 BP. These high levels may correspond to an increase in precipitation in this region during these periods and drier during the subsequent Holocene period.

Pollen samples were collected and sampled from the Alero El Puesto (AEP-1) archaeological site at the Piedra Museo locality (Borromei 2003). The chronology for this sequence was based on 4 radiocarbon ages. This record also indicates two major shifts in vegetation during the Pleistocene-Holocene transition from around 12,890-7670 BP. First, around 11,000 BP there is a shift from Asteraceae shrub steppe to a Poaceae grass steppe which indicates that cooler conditions with increases in effective moisture prevailed. The second shift occurred around 9500 BP when the grass steppe was replaced by an *Ephedra* and Asteraceae shrub steppe indicating an increase in temperature and precipitation.

### ***Flooding and Modern Regulation of the Negro, Limay, and Neuquén Rivers***

Flooding throughout the period of human occupation in the Río Negro Valley not only had an impact on the landscape history of the valley, but also may have had a direct influence on human settlement patterns. This possibility will be explored in subsequent



chapters. In the 20<sup>th</sup> century, the hardships caused by large-scale flooding in the Río Negro Valley has resulted in regulation of the three fluvial systems (Limay, Neuquén, and Negro) through dam construction on the Limay and Neuquén Rivers. This began in the 1960s.

The fluvial regime of the Río Negro is strongly influenced by its two tributaries (Río Limay and Río Neuquén) (Figure 5) and their variations in discharge. The average discharge for the Río Limay is 700 m<sup>3</sup>/s although it can vary seasonally from 300-1,700 m<sup>3</sup>/s due to increases in winter precipitation and meltwater influx (Acevedo 1981). In contrast, the average discharge for the Río Neuquén is 300 m<sup>3</sup>/s although seasonal variation ranges from 100-600 m<sup>3</sup>/s. Meltwaters that flow into the Río Neuquén originate from a complex drainage network of Andean tributaries which are also susceptible to fluctuations in precipitation and meltwater. As a result, the majority of discharge that flows into the Río Negro at its confluence originates from the Río Limay, whereas the majority of sediment load derives from the Río Neuquén at a rate of 13 x 10<sup>6</sup> tons, (117.091 x 10<sup>9</sup> kg) per year, which accounts for its general muddiness (Frangi and Malacalza 1978).

### ***Modern Flooding History***

For more than 200 years, historical records indicate that the Río Negro Valley has experienced major flood events with frequency. Floods have been documented in the following years: 1779, 1833, 1845, 1879, 1899, 1900, 1911, 1914, 1915, 1930, 1932, 1937, 1940, and 1945 (Soldano 1947). The catastrophic floods in 1899 and 1900

resulted in flooding of the Río Negro Valley and the discharge during these events was recorded at 10,000 m<sup>3</sup>/s. The 1899-1900 flood events had major effects on the valley as they destroyed entire populations, crops, and the railroad. The entire valley flooded, even the city of Viedma which is situated along the Río Negro but is 30 km inland from the coast (Figure 10). The destruction caused by these floods to local residents, farmers, and ranchers instigated the construction of a series of dams along the Río Limay and Río Neuquén to regulate the impact of such large flood events.



**Figure 10.** Downtown Viedma. Prates is pointing to a plaque indicating the water level during the flood of 1899.

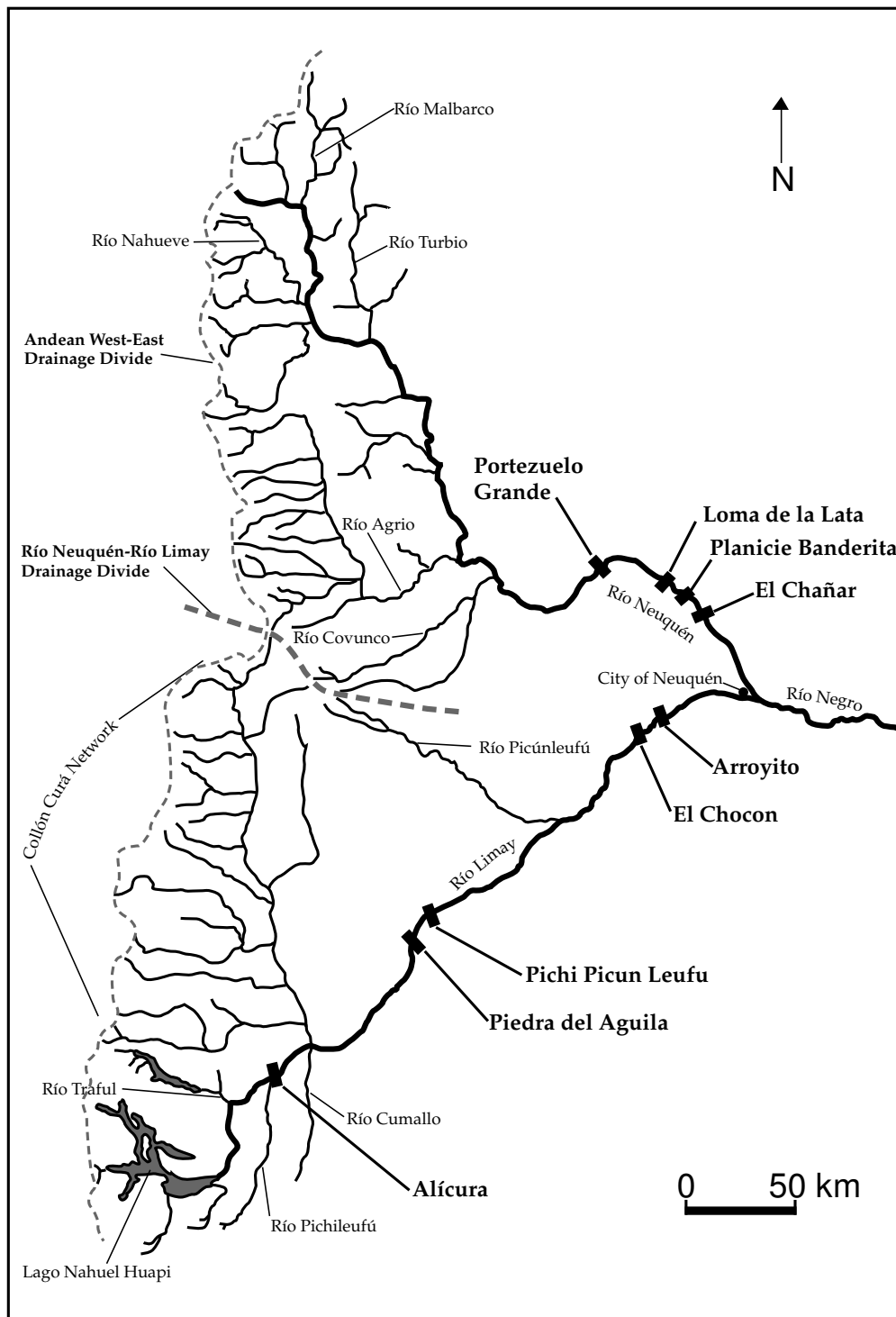
Twelve gauging stations were installed along these three rivers in the early 1900s in order to monitor the fluvial regimes (Soldano 1947). The Paso Limay Station

provides data on the Río Limay from 1903-1990, the Paso de Indios Station provides data on the Río Neuquén from 1903-2004, and the Primera Angostura Station provides data on the Río Negro from 1928-2004. All of these data were obtained from engineer Carlos Merg in the Departamento Provincial del Agua del Provincia del Río Negro (Provincial Water Department of Río Negro) in Viedma.

Based on these data and the general regime characteristics, the Río Neuquén is a flashy or torrential regime in comparison with the Río Limay because it does not drain from glacial lakes which can act as a buffer for any large seasonal water influx. Therefore, discharge increases are sudden and often violent. The abrupt increases occur twice a year as a result of autumn rainfall and spring snow melt in the mountains. The regime of the Río Limay is regulated by 37 glacial lakes within its drainage network. These lakes can swell to accommodate their increased capacity, acting like natural reservoirs, and release waters into the Río Limay system at a much slower rate. Therefore, the Río Limay has a comparably smaller or more gradual influence on the flooding of the Río Negro as compared to the Río Neuquén.

### ***Dam Construction and River Regulation***

Construction of a series of large dams, dikes, and reservoirs along both the Río Limay and Río Neuquén began in the mid 20<sup>th</sup> century (Figure 11 and Table 5). Altogether, these dams generate a significant portion of hydroelectricity for the Buenos Aires province at an estimated 2,700,000-4,700,000 kw/yr (Acevedo 1981). Gonzalez Diaz y Malagnino (1984) claim that dam construction and irrigation have made a major



**Figure 11.** Locations of river dams along the Río Limay and Río Neuquén.

Table 5. Dams and Dikes on the Río Limay and Río Neuquén.

Dam or Dike	River	Height (m)	Length (m)	Reservoir Surface (km <sup>2</sup> )	Vol. Hm <sup>3</sup>	Annual Ave. (GWh)	Max. discharge (m <sup>3</sup> /s)
Alicura	Limay	120	900	65	3,215	2,360	3,000
Piedra del Aguila	Limay	170	870	261	12,400	5,230	10,000
Pichi Picun							
Leufu	Limay	45	1,050	18	197	1,000	10,000
El Chocon	Limay	86	2,500	816	20,200	3,300	8,000
Arroyito	Limay	37	3,500	39	296	720	3,750
Portezuelo							
Grande	Neuquen	15	3,200	--	--	--	3,600
Loma de							
la Lata	Neuquen	16	1,500	610	27,770	--	800
Planicie							
Banderita	Neuquen	34	300	--	13,800	1,500	--
El Chañar	Neuquen	16	6,670	--	35	--	--

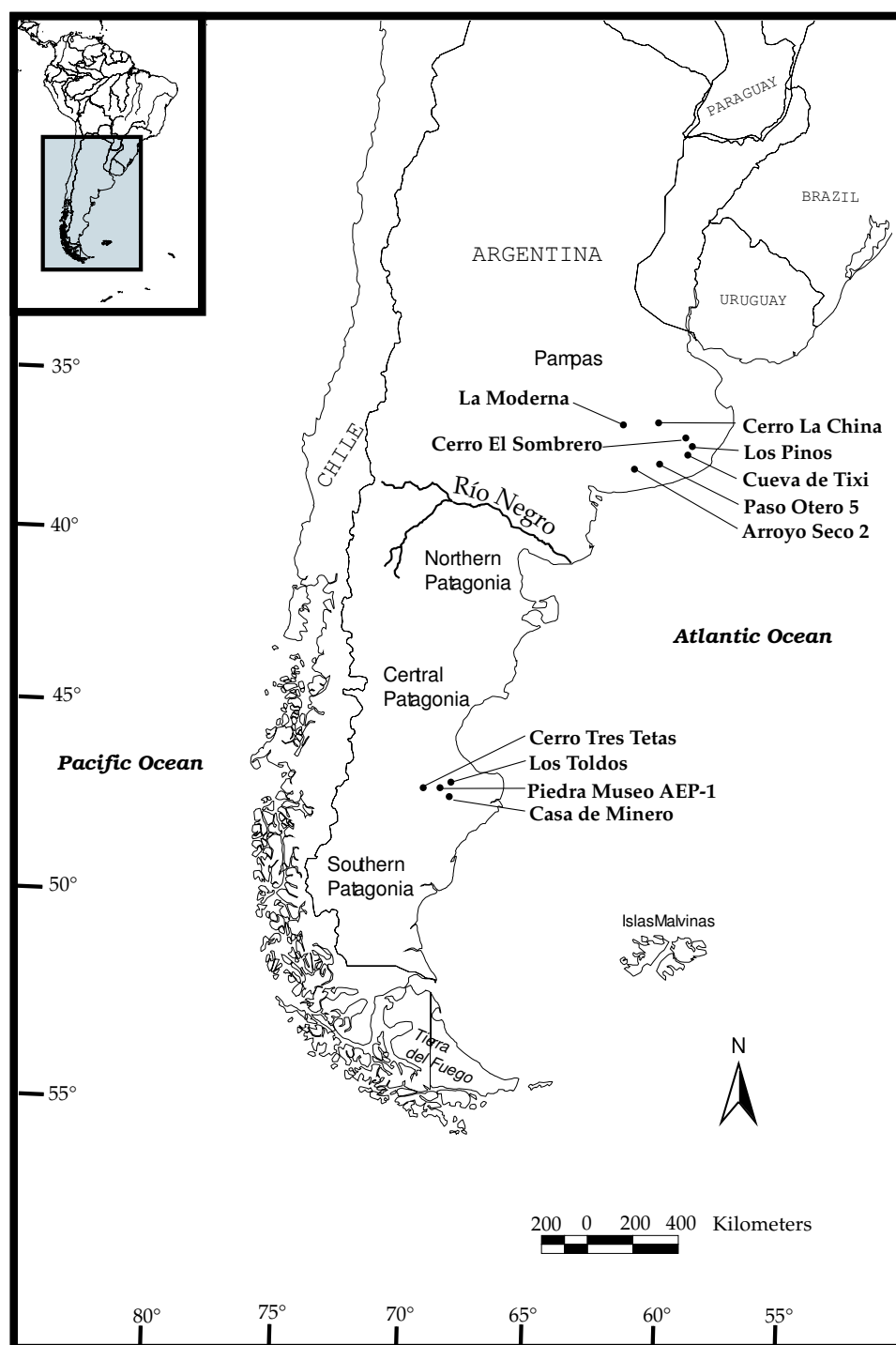
impact on the modern Río Negro. Although dams certainly affect discharge and sediment load, the response or adjustment by channels downstream from dams can vary depending on the original sediment load and flow regimes of the channels in comparison to the new regime (Kondolf 1997). In addition, dams can regulate flood frequency and the nature of sediment load (Petts 1979; Williams and Wolman 1984). Although there is certainly some impact on the Río Negro as a result of regulation, modern data indicate that it has a stronger impact on the regulation of flooding rather than on annual discharge.

## **Archaeology of the Southern Pampas and Northern Patagonia**

### ***Initial Colonization of the Pampas (12,200-10,000 RCYBP)***

Current evidence indicates that the Pampas were initially colonized by humans as early as 12,200 RCYBP (Politis, et al. 2004). These Late Pleistocene groups were bands of hunter-gatherers who were highly mobile and adaptable to a wide range of environments. They manufactured lithic tools both from local and exotic primary material. Their diet was generalized and consisted of a variety of fauna including several species of extinct mega-fauna (e.g., giant ground sloth and an extinct species of horse) although the guanaco was most commonly exploited and a mainstay of their diet. Use of the Fishtail Projectile Point technology became widespread throughout the Pampas from 11,000-10,000 BP. Late Pleistocene and Early Holocene hunter-gatherers have been classified as groups that exploited a wide variety of resources throughout the region. For example, of the 38 faunal species recorded at archaeological sites, 16 of those species were consumed. This has been categorized as a “generalized regional economy” (Martínez and Gutiérrez 2004).

The earliest dated archaeological site in the Pampas is the Arroyo Seco Site, a large open-air campsite which was first inhabited between 12,240-10,500 BP (Figure 12 and Table 6). This site was re-occupied numerous times until the Late Holocene. The earliest occupation consists of quartzite and flake tools associated with the bones of extinct species of *Megatherium* and *Equus* spp. Analysis of these bones indicates the helical fractures on numerous long bones are the result of marrow processing and were therefore modified by humans (Gutierrez 2004). The radiocarbon dates were based on



**Figure 12.** Archaeological sites mentioned in the text.

Table 6. Radiocarbon Samples from the Arroyo Seco Site from the Lowest Level.

Site	Radiocarbon Age (AMS)	Lab Number	Material Dated
Arroyo Seco 2	12,240 ± 110	CI OXA-4591	Bone
Arroyo Seco 2	12,200 ± 170	CAMS-58182	Bone
Arroyo Seco 2	11,750 ± 70	CAMS-16389	Bone
Arroyo Seco 2	11,590 ± 90	AA-7965	Bone
Arroyo Seco 2	11,250 ± 105	AA-7964	Bone
Arroyo Seco 2	11,000 ± 100	OXA-4590	Bone
Arroyo Seco 2	10,500 ± 90	AA-9049	Bone

samples taken from these bones. In addition to the lithics and faunal remains, various fragments (n=52) of red ochre were found in the earliest levels of this site (Politis and Gutierrez 2006). Some of these ochre pieces have clear evidence of usewear. Their color and prevalent use throughout the Pampas may suggest that red ochre possessed symbolic meaning to the early colonizers of the Pampas (Scalise and Di Prado 2006).

Buried in the floodplains of the Quequén Grande River, another Late Pleistocene site was excavated which was first inhabited around 10,440 BP (Table 7). The Paso Otero 5 site was interpreted as a processing location for extinct megafauna due to the significant amount of burnt and calcinated bone from at least 11 megafauna (Martínez, et al. 2004). Found among these bones were two fragments of Fishtail points and several flakes.

Table 7. Radiocarbon Samples from the Paso Otero 5 Site.

Site	Radiocarbon Age (AMS)	Radiocarbon Age (Conventional)	Lab Number	Material Dated
Paso Otero 5	10,440 ± 100		AA-39363	Bone
Paso Otero 5	10,190 ± 120		AA-19291	Bone
Paso Otero 5		9,399 ± 116	DRI-3573	Organic material



Fishtail projectile points have also been found at numerous sites in the Pampas, particularly in the small mountain range of Tandilia which is to the northeast of the Arroyo Seco and Paso Otero 5 sites. A majority of these sites are rockshelters containing archaeological material and eight of those sites date to the Late Pleistocene- Early Holocene Transition, between 11,000-10,000 BP (Table 8). These sites include: Cerro La China 1 (Flegenheimer 1987; Flegenheimer and Zárate 1997); Cerro La China 2 (Zárate and Flegenheimer 1991); Cerro La China 3 (Zárate and Flegenheimer 1991); El Sombrero Abrigo 1 (Flegenheimer 1995, 2003); Cueva Tixi (Mazzanti and Quintana 2001); Abrigo Los Pinos (Mazzanti 1999a); and Cueva Burucuyá (Mazzanti 1999b).

Table 8. Radiocarbon Samples from Various Archaeological Sites in the Tandilia Mountains.

Site	Radiocarbon Age (AMS)	Radiocarbon Age (Conventional)	Lab Number	Material Dated
Cerro La China 1	10,804 ± 75		AA-8953	Charcoal
Cerro La China 1	10,790 ± 120		AA-1327	Charcoal
Cerro La China 1	10,745 ± 75		AA-8952	Charcoal
Cerro La China 1	10,720 ± 150		I-12741	Charcoal
Cerro La China 1	10,525 ± 75		AA-8954	Charcoal
Cerro La China 2	11,150 ± 135		AA-8955	Charcoal
Cerro La China 2	10,560 ± 75		AA-8956	Charcoal
Cerro La China 3	10,610 ± 180		AA-1328	Charcoal
El Sombrero Abrigo 1	10,725 ± 90		AA-4765	Charcoal
El Sombrero Abrigo 1	10,270 ± 85		AA-4766	Charcoal
El Sombrero Abrigo 1	10,675 ± 110		AA-4767	Charcoal
El Sombrero Abrigo 1	10,480 ± 70		AA-5220	Charcoal
El Sombrero Abrigo 1	8,060 ± 140		AA-5221	Charcoal
Cueva Tixi	10,375 ± 90		AA-12130	Charcoal
Cueva Tixi	10,045 ± 95		AA-12131	Charcoal
Abrigo Los Pinos	10,465 ± 65		AA-24045	Charcoal
Abrigo Los Pinos		9,570 ± 150	LP-630	Charcoal
Abrigo Los Pinos		8,750 ± 160	LP-684	Charcoal
Cueva Burucuyá		10,000 ± 120	LP-863	Charcoal

The rockshelter sites were likely occupied by the same groups occupying open air interserrana sites such as the Arroyo Seco Site and the Paso Otero 5 Site (Politis 2006). The rockshelters would have been occupied for short periods by a single or partial band in order to gather raw material, hunt small fauna, or other specialized tasks. The interserrana sites would have been occupied for longer periods where several bands might live together to perform tasks requiring collaboration between bands such as hunting megafauna (Politis and Madrid 2001).

### ***Summary of the Peopling of the Pampas***

At this point, although not all regions of the Pampas have been extensively investigated by archaeologists, nevertheless, it appears that the earliest archaeological sites in this region are concentrated in the mountains (e.g., Tandilia) or their adjacent plains (the interserrana region) (Politis, et al. 2004). This suggests that the earliest groups living in the Pampas were dependent on the mountains for their lithic raw material. For example, orthoquartzite and chert are the most widely used from this region although rhyolite from the Ventana mountains and coastal gravels have also been found at these sites. The same may be true for the nearby Ventana mountains. However, this region has not been intensively and systematically investigated by archaeologists and very little information exists about the archaeology of this region. One possibility is that, in other regions of the Pampas, technology was based on wood and bone as the primary material for tool manufacture, but this issue needs to be investigated in the future. On the other hand, exotic or extra-regional primary material

was also found at these sites, including a reddish silicified sandstone found at the Cerro La China and El Sombrero sites, which has been sourced to southern and central Uruguay (Flegenheimer, et al. 2003).

Based on a variety of evidence (e.g., technology, primary material used for lithic manufacture, settlement patterns, and chronology), it appears that sites from this period located in the Tandilia mountains and the adjacent Pampean plains were occupied by the same groups of hunter-gatherers (Martínez 1999). However, although sites in both regions were occupied by the same people several major differences are evident in the social organization, mobility, and exploitation of the environment between the two regions (Politis, et al. 2004).

The Arroyo Seco 2 open-air site is interpreted as a base camp which was repeatedly occupied. Archaeological and faunal evidence from this site indicates that it was used as a staging ground for groups to gather for conducting cooperative hunting expeditions necessary for hunting certain megafauna species. In addition, it was used during group consumption of these resources. Space was not restricted in this region and therefore site remains are widely dispersed in comparison to the Tandilia mountain sites. The Paso Otero 5 site has been interpreted as a secondary processing site for Pleistocene megafauna (Martínez 1999).

The caves and rockshelters in the Tandilia mountains were used and occupied in a different manner during this period (Politis, et al. 2004). Because space was much more restricted, habitable space at these sites was not abundant and therefore these sites were occupied by smaller groups (e.g., 1-2 family groups). Faunal remains found at

these sites were different as well. Only the remains of small to mid-sized animals were found at these sites which easily could have been hunted by individuals or small family units.

Therefore, Politis et al. 2004 propose a model for the peopling of the Pampas. Family groups aggregated at open-air sites located in the Pampean plains such as at Arroyo Seco 2 and Paso Otero 5 in order to carry out cooperative activities which would require larger groups (e.g., the cooperative hunting of megafauna). Possibly on a seasonal basis, these large bands would separate into small groups for short periods to travel up into the Tandilia mountains in order to procure primary materials and hunt smaller animals common to that environment (Politis and Madrid 2001).

In addition, based on similarities in lithic technology and the presence of primary material from extra-regional sources, this suggests that the earliest human groups occupying the Pampas maintained regular interaction with groups occupying other regions. Fishtail projectile points have been found throughout the Pampas and Patagonia as well as Chile and Uruguay. In addition, sites in the Pampas contain artifacts made from raw material which has been sourced to southern and central Uruguay, (Flegenheimer, et al. 2003).

***Early Holocene Population Increase, Survival of Extinct Megafauna, and Exploitation of Marine Resources***

Towards the end of the Early Holocene the first evidence in the Pampean plains appears for human exploitation of marine resources at the sites of La Olla 1, La Olla 2, and Monte Hermoso (Bayón and Politis 1998; Fontana 2004). These sites are all located within lacustrine deposits in a coastal environment. The La Olla sites were interpreted as seal processing sites and the Monte Hermoso site contained hundreds of human footprints. Eleven radiocarbon samples from these sites were dated between 7,900-6,600 BP.

One aspect of the Pampas which may be unique to this region, is the evidence for megafaunal survival into the Early Holocene. Two sites, the La Moderna site and Campo Laborde site both yielded artifacts associated with megafaunal bones. The La Moderna site was dated between 7,500-7,000 BP (Politis, et al. 2003) and the Campo Laborde site dated to 8,800-7,800 BP (Mesineo and Politis 2006). This suggests the Early Holocene humans coexisted with these megafauna species and these fauna served as a part of their diet until their extinction.

***Middle Holocene Climate Change and Regional Specialization***

The archaeology of the Middle Holocene in the Pampas can not be discussed without understanding the climatic context during this period which was characterized by significant changes. The Middle Holocene Hypsithermal occurred during this period resulting in a significant rise in sea level around 7,000 BP which was higher than

modern levels although the exact degree of level change is still under discussion (Politis 2006). In addition, the climate became warmer and more humid although interrupted with brief dry periods.

A majority of the archaeological sites in the Pampas during the Middle Holocene (e.g., Cueva Tixi, Cerro La China, Avestruz, El Abra, Casa de Piedra, Tapera Moreira) based their economy on the exploitation of guanaco rather than the wider range of resources exploited during the Early Holocene (Politis 2006). Martinez and Gutierrez (2004) have classified this period as a specialized regional economy where from the 34 taxa recovered from archaeological sites, only 10 species were exploited. Technology during this period consisted of bola stones, triangular projectile points, and grinding stones.

The Arroyo Seco 2 site and the Fortín Necochea site offer the most comprehensive archaeological data for this period because they were reoccupied and illustrate technological sequences for this region. These open air sites have been interpreted as residential base camps. The Fortín Necochea site dates between 6,000-3,600 BP where guanaco was exploited as a primary resource and deer, rhea (South American ostrich), and armadillo were consumed secondarily.

At the Arroyo Seco 2 site, 45 human skeletons were excavated and 19 radiocarbon dates age this portion of the site from 7,800-4,800 BP (Politis 2006). The earliest burials contained triangular projectile points embedded within the skeleton cavities. Grave goods were found in the later burials (ca. 7,600 onwards) such as necklaces of canid (possibly fox) canines, beads made from marine shells, and red ochre.

These elements within this context have been interpreted as having a highly symbolic value to these groups and also indicate that these burials were ritualistic. Human burials occurred at the Arroyo Seco 2 site for more than 3,000 years. In addition to evidence for Middle Holocene technology and subsistence in the Pampas, altogether this offers a rare view of the continuum of transition from the Early Holocene to Middle Holocene in this region.

### ***Diversification and Intensification in the Late Holocene***

In the Late Holocene (3,500-500 BP) although mobility of groups decreased, a number of developments appeared including: wide networks between groups, appearance of exotic artifacts (e.g., elaborately engraved stone plaques), pottery (3,000 BP), the bow and arrow (3,000 BP), horticulture, and social complexity (Politis 2006). The economy of this period has been classified as the diversification and intensification of area economies (Martínez and Gutiérrez 2004).

In the Pampas, regionalization in adaptive patterns appeared between the hunter-gatherers of the xerophitic forest and the open grasslands. Sites which are classified as part of the xerophitic forest include Casa de Piedra, Tapera Moreira, El Tigre, and Chenque 1. These sites indicate that guanaco continued to be the primary resource which was supplemented by deer, rhea (ostrich), armadillo, and fish (at coastal sites and sites near rivers), and grinding stones found at these sites suggest that local fruit (i.e., *Geoffre decorticans*, *Prosopis sp*) was also consumed (Politis 2006). The Chenque 1 site is a large cemetery where 700 skeletons have been discovered in 2 levels within a

complex stone structure (Berón, et al. 2006). It is interpreted while this site was repeatedly used between 1,030-370 BP, this served as a means to reinforce access to certain resources (Berón 2004).

Archaeological sites of the grassland hunter-gatherers are widespread and numerous although they are most commonly found on the periphery of freshwater lakes (i.e., Fortín Necochea, Laguna El Trompa, Los Chilenos 1 and 2, and Laguna Puán) and rockshelters (i.e., Cueva Tixi and Cerro La China) (Politis 2006). Until ca. 1,000 BP, guanaco was the principal resource. Pottery among these groups appeared around 3000 BP (Politis, et al. 2001). Lithic technology consisted of unifacial tools, bola stones, and the development of small triangular project points which signal the introduction of the bow and arrow (Politis 2006). Martinez (1999) proposed that the economic and social intensification that occurred during this period was caused by changes in mobility, subsistence, and technology (Martínez 1999). The adoption of certain technological innovations, such as pottery, corresponds with an increase in social complexity (Politis, et al. 2001). These inland groups periodically traveled to the coast and adapted to the exploitation of coastal resources where marine fauna (e.g., fish, seal) supplemented their diet and beach cobbles served as another source for lithic technology (Bonomo 2005a, b). Exotic materials such as pottery from the Pacific coast (i.e., Chile), lip and ear plugs, beads, semi-precious rocks from other regions, and Patagonia engraved stone plaques, all suggest fairly extensive exchange networks between groups on a regional and extra-regional basis (Politis 2006).



Extensive cave painting has also been discovered throughout the Pampas. Although none of these sites have been directly dated, they are generally discussed as part of the Late Holocene archaeology of the Pampas because stylistically it resembles much of the Late Holocene rock art from northern Patagonia. They are found throughout the Tandilia, Ventania, and Lihue Calel mountains (Madrid and Oliva 1997). Paintings have included geometric designs, anthropomorphic images, and animal footprints which indicate a complex development of Pampean cave art in the Late Holocene and have been interpreted as serving as territorial markers, ritual signs, or places of social aggregation (Oliva and Algrain 2004).

### ***Recent Investigations of the Pampean Coast and Northern Patagonia***

Along the Atlantic coast, a recent survey was conducted along the coastal plains of the Interserrana region of the Pampas (Bonomo 2004, 2005). A number of archaeological sites were recorded during this survey and analysis of the use of space indicated that these coastal sites were occupied by the same cultural groups which occupied sites further inland on the Pampas. In the lower valley of the Río Colorado, north of the Río Negro, based on survey and excavation of a number of archaeological sites, a recent synthesis of the regional archaeology has been presented as well as a model for Late Holocene adaptive strategies and populations (Martínez 2006). In the southern Pampas, the result of another extensive investigation has yielded a regional model on the use of space for the Late Holocene (Berón et al. 2006). Along the coast of the Río Negro province, an extensive survey has been conducted (Favier Dubois 2006).

This survey recorded 88 archaeological sites (currently undated) which were interpreted as the remains from small groups of mobile hunter-gatherers who exploited a variety of resources.

## **CHAPTER III**

### **METHODOLOGY**

#### **Introduction**

The pre-cursor to interpreting the geological context of the archaeological record or evaluating the impact of site formation processes on archaeological sites is a detailed reconstruction of the landscape history for a region. Field methodology for data collected was composed of various strategies for recording the vertical and horizontal elements that allowed a comprehensive reconstruction of this history from the Late Pleistocene-Holocene for ca. 150 km of the Middle Río Negro Valley.

Late Quaternary landscape history can be represented by a 3-dimensional block of stratified sediments. For the purposes of archaeology, geoarchaeology only focuses on sediments down to pre-human bedrock. Regardless of size, this sediment block represents time, sequences of sediment deposition, erosion of these sediments, and/or soil formation which transforms certain features of these sediments. Each process (deposition, erosion, and soil formation) requires a period of time. This sequence of events is repeated in any given location across the valley from the origin of valley construction and continues today. Reconstruction of the sequence and timing of these events creates a landscape history.

However, the simplified sediment block falls short in representing the whole history of the Middle Río Negro Valley because this history is often not represented by horizontally buried sediments alone. In this case, an important portion of the Late

Holocene landscape history was horizontally distributed in discrete packets across the landscape in the form of abandoned river channels which formed when the Río Negro shifted its course to another part of the valley. This occurred at least three times during the Late Holocene. Therefore, the methodology used in reconstructing the landscape history of this valley focused on recording both stratigraphic sequences from the valley bottom to the present surface and at various localities across the study region in order to capture these lateral relationships. The result was a comprehensive reconstruction of the landscape history from the Late Pleistocene through Holocene in the form of a geomorphic map and generalized stratigraphic cross section. Geomorphic maps are a representation of the two dimensional modern surface. They classify each surface deposit or landform and illustrate their distribution (or absence) throughout a region (Davidson 1985; Haynes 1964). Accompanying explanations may include descriptions of the sedimentological characteristics of each deposit and chronological information.

As a result, it is then possible to fully understand the geological context of the archaeological record. This includes the ability to predict the location of sites through time and evaluate site formation processes and the preservation and visibility of the archaeological record. This chapter outlines the methodology used in this project for general reconnaissance, field recording and data collection for the first field season (October 2005-February 2006), laboratory methods for sedimentological analysis, and final data collection of the second field season (September-October 2006).

### **Reconnaissance Methods**

Field reconnaissance of the study region was necessary in order to devise an effective field recording strategy. This was accomplished in three stages. First, the study region was visited in March 2004 in order to become familiar with the general landscape features, define the study area in collaboration with the archaeologist for this region (Lic. Luciano Prates), and determine the sedimentological focus for landscape reconstruction. In this case, this consisted of the fluvial and eolian sedimentary deposits of this study region.

The second stage was the research phase of the reconnaissance. This involved study of topographic and geological maps along with aerial photographs of the study region. Topographic maps from the 1980s were obtained in Buenos Aires from the Instituto Geográfico Militar, Republica Argentina-IGM (Geographic Institute of the Argentine Military). Maps on a scale of 1:100,000 and 1:250,000 with 10 m topographic contour intervals were studied. The specific maps used with a 1:100,000 scale include: Lamarque, Hoja 3966-28 (1983 edition); Establecimiento Los Paraísos, Hoja 3966-34 (1983 edition); Colonia Josefa, Hoja 3966-29 (1984 edition); El Solito (Pje.), Hoja 3966-35 (1984 edition); and Colonia Chocori, Hoja 3699-36 (1983 edition). The two maps with a scale of 1:250,000 were Villa Regina, Hoja 3966-III (1997 edition) and Choele Choe: Hoja 3966-IV (1997 edition). Recent geological maps were obtained from the Servicio Geológico Minero Argentino- SEGEMAR (Argentine Mineral Geology Service). All are 1:250,000 and were published in 1999 as *Geología y Recursos Minerales de la Hoja 3966-IV* (Suriano, et al. 1999). A brief and general description of

the Miocene-Holocene stratigraphy, geomorphology, historical geology, and mineralogical resources included with these maps was also consulted as a general reference. However, they did not offer the level of detail required for this landscape reconstruction, thus necessitating the detailed field recording conducted by this project. Black and white aerial photographs taken in 1978 and 1986 were also obtained from the Instituto Geográfico Militar in Buenos Aires.

Topographical and geological maps were scanned into a digital format and were imported into Adobe Illustrator. Using these maps as a base map along with study of the aerial photographs, a geomorphologic map was drawn. This map identified the necessary elements of landscape reconstruction: permanent landforms (e.g., meseta), stabilized surfaces (e.g. fluvial terraces above the modern floodplain, developing surface soils, abandoned avulsion channels and meanders), and dynamic zones (e.g., the modern river channel and floodplain) (Waters 1992). Tertiary sediments (bedrock and bedrock covered with eolian sediments), Pleistocene sediments (channel and floodplain deposits of the proto Río Negro and alluvial terraces within the valley confines), and Holocene sediments (sand sheets, lacustrine, colluvial, and floodplain deposits covered by eolian deposits) were designated by various colors to differentiate these various deposits on the geomorphic map.

The third phase of reconnaissance took place during the initial portion of the first field season. Field reconnaissance first consisted of resolving potential logistical problems for conducting field research by evaluating accessibility throughout the study region. This involved extensive contact with landowners to explain the purpose of

fieldwork and establish trust in order to gain permission to enter their property. In addition, this phase included locating new and old dirt roads across the region which were not always designated on maps, the identification of passable gates between landowners, obtaining keys for locked gates, and evaluating newly bulldozed dirt roads that allowed access to regions only accessible by foot (i.e., depth of loose sand cover and water cover following storms). Following this stage, field reconnaissance began to locate potential stratigraphic profiles for recording which would represent the study area. Profiles were located in drainage gullies that cut perpendicular to the valley axis, natural crevices (e.g., cuts perpendicular to avulsion channels), gravel mines for road construction, cutbanks along each avulsion channel, profiles along fluvial terraces above the modern floodplain, and along the modern river channel cutbanks. The specific boundaries of the meseta plateau edge and Pleistocene terraces were located through field checks as well and recorded by GPS. Pleistocene terrace boundaries were located by running a transect from the southern meseta boundary northwards until reaching the first Holocene terrace ( $T_1$ ). There were two final goals for field reconnaissance before initiation of field recording. The first was to evaluate the potential for the proposed dating methods by searching for datable material (i.e. organics for radiocarbon dating and preserved sand deposits for OSL dating) and sampling locations. The second goal was to understand the general nature of the archaeological record in the field; for example, the density of archaeological material and basic patterns in its visibility and location within the landscape.

Field recording began with this general overview of the study region. This was achieved through three phases of field reconnaissance which were necessary to develop an effective strategy for collecting the necessary data with time, accessibility, and logistical constraints. This project progressed into the next stage of field recording with an overview of the geology, geomorphology, and archaeological records, as well as a sampling strategy that would allow reconstruction of the Late Pleistocene through Holocene landscape history.

## **Field Recording and Data Collection**

### ***Recording Sediments and Soils***

At each stratigraphic profile site as well as every archaeological site and significant landscape feature (e.g., sand dunes, pools, etc.), a GPS waypoint was recorded and each location was assigned a unique number (e.g., WP 264). Each section was photographed to illustrate detailed characteristics in addition to its landscape context. At each profile, a Geological Section Recording form was completed and also given a unique number. First, stratigraphic units were delineated and assigned a number (e.g., Unit 1). Unit and deposit thickness were measured and recorded. If a soil was present, this was noted as well as whether it was a surface or buried soil horizon. Each unit contact was classified by its distinctness (abrupt, clear, gradual, or diffuse) and topography (smooth, wavy, irregular, and broken). Sediment texture was determined for gravel or non-gravel sediments (Folk 1954) in the field and selective samples were submitted for formal particle-size distribution analysis at the Soil Characterization Lab at



Texas A&M University. Sediment color was determined using the Munsell Soil Color Charts for each sediment both on a dry and wet basis. In addition, the following characteristics were recorded: structure (laminated, graded, massive, cross-bedded, interfingering, lens); composition (quartz, feldspar, arkosic, or other inclusions); sorting (very well, well, moderately, poorly, very poorly); dry consistence (loose, soft, slightly hard, hard, very hard, extremely hard); wet consistence-stickiness (nonsticky, slightly sticky, sticky, very sticky); wet consistence-plasticity (nonplastic, slightly plastic, plastic, very plastic); HCl reaction (none, audible, moderate, persistent, strong); coatings (none, carbonates, iron oxides, manganese oxides, clay skins, root molds); secondary particles (none, nodules, concretions, crystal aggregates, other); and inclusions (none, artifacts, bones, roots, shells, charcoal, other). Any additional characteristics of the profile were noted and limited interpretation in the field was also conducted, e.g., preliminary identifications of depositional unit type such as whether it was fluvial (overbank, floodplain, or channel deposit) or eolian (loess or dune deposits). Unit contacts were inspected to determine whether they were conformable or unconformable (e.g., due to erosion). Erosional contacts were examined and recorded in detail.

Each soil observed in the field was recorded using a Soil Profile Recording form. This form follows the guidelines described in the USDA Soil Survey Manual (1993) and is based on one developed by pedologist Dr. Charles T. Hallmark of the Soil and Crop Sciences Department, Texas A&M University. As with each stratigraphic profile, the GPS waypoint was recorded and detailed soil characteristics photographed. Each soil was classified as a surface or buried soil and the depth of the buried soil surface and soil

thickness were measured. Each soil was divided into master soil horizons and assigned a soil horizon classification (e.g., A, B, or C horizon) as well as a subsurface horizon (e.g., t, k, etc.) according to Keys to Soil Taxonomy (2003). Horizon depth was measured and boundary distinctness and topography were evaluated. Field texture of each horizon was categorized and at each horizon, Munsell color was assigned. The abundance and contrast of redox features was recorded along with their structure grade and type. Dry and moist consistence was recorded as well as any additional features. The profile characteristics were also recorded in terms of landform (modern floodplain, first terrace, second terrace, plateau), parent material (alluvium, colluvium, residuum), erosion (none to slight, moderate, severe), and slope (0-1% level or near level, 1-3%, 3-5%, 5-8%, 8-12%, and 12%+). Each soil was classified on the basis of its epipedon (mollic, ochric, none), subsurface horizons (argillic, cambic, calcic, slickensides, none), and order (Histosol, Spodosol, Andisol, Oxisol, Vertisol, Aridisol, Mollisol, Ultisol, Alfisol, Inceptisol, Entisol). Finally, any additional features were also noted.

Sedimentological samples were collected to answer specific questions such as determining the difference between fluvial and eolian agents of deposition through particle-size distribution and optically stimulated luminescence (OSL) analysis (Steve Forman, personal communication). Such aspects were not always clear in the field. Samples were collected for both particle size distribution (PSD) and petrography. If organic material was present and appeared viable for radiocarbon dating, collected samples were recorded *in situ*, wrapped in aluminum foil, labeled, and stored in film canisters and plastic bags. Samples for OSL dating were also recorded *in situ*, collected

using a 15 cm segment of white PVC pipe which was wrapped with duct tape, hammered into the profile, removed, and sealed with additional duct tape. A sediment sample was also collected around the 15 cm perimeter of each OSL sample.

### ***Recording Geomorphological Features of the Modern Surface***

Several land features were integral to reconstructing the landscape history. These features include abandoned channels which formed as a result of channel avulsion, flood channels located within and between avulsion channels, pools which formed within avulsion channels, and eolian deposits (loess and dunes).

Three avulsion channels were identified in this region (Avulsion channels 1, 2, and 3). In the field and through study of aerial photographs, the general characteristics of each were recorded at a representative number of locations including: lateral and terminal boundaries of each avulsion channel, sinuosity prior to avulsion, density of abandoned meanders along the length of each avulsion channel, degree and composition of modern channel fill, soil development on fluvial sediments, eolian capping of fluvial sediments, and the relative chronological sequence of the three channels. Flood channels were identified as following the inner course of avulsion channels as well as cutting across inter-avulsion channel deposits following courses they had formed independently. In the field, these flood channels were differentiated from the larger avulsion channels and their morphology was recorded (e.g., lateral and terminal boundaries, sinuosity, presence of abandoned meanders, channel fill). They were also placed into a relative chronological sequence in relation to the avulsion channels.

During the initial field reconnaissance, the presence of pools was noted in a number of locations within avulsion channels. The pools were located within abandoned avulsion channels and were commonly found inside meander bends. Their formation was not clear, although the density of these pools along each avulsion channel was hypothesized to have had a potential impact on human settlement patterns within the region. Therefore, they were also recorded. More than 40 pools were identified on aerial photos and 28 were investigated and recorded in detail: 9 pools within Avulsion channel 1, 10 pools within Avulsion channel 2, and 9 pools within Avulsion channel 3. The following was recorded for each pool: GPS location, dimensions, whether the pool presently contained water or was dry, the presence of fresh or saline water, fauna inhabiting the pool itself or nearby, type of vegetation as well as its size and density, the character and steepness of avulsion channel banks confining the pool (e.g., steep or gradual, dune sand stabilized by vegetation), the presence of redeposited channel gravel closely beyond the downstream distal end of the pool, and the presence of archaeological material in the pool vicinity. A cross-section sketch was also made at a majority of the locations. Sedimentological samples were collected from pool sediments to compare to fluvial and eolian sediments in the region. Micromorphological and pollen samples were also collected for future analyses. General field interpretations were also made in terms of whether each pool appeared to contain water on a fairly permanent basis. The presence of permanent water could suggest that they intersect the water table. On the other hand, some pools could simply be a temporary collection of rainwater that was perched above eolian sediments that collect within the avulsion channel. Certain

segments along each avulsion channel were surveyed to establish any patterns in the formation of these pools. The general character of these patterns was also recorded.

One aspect observed during field reconnaissance was the predominance of eolian sediments deposited over the majority of exposed and stabilized surfaces in the middle valley of the Río Negro. These sediments were observed as the loess mantle deposits that commonly cover fluvial sediments and large sand dunes which were observed throughout the 150 km segment of this valley. Thirty-three loess sediment samples were collected from stratigraphic profiles as well as from surface localities throughout the region for comparison to these stratified sediments. Dune sediments were also collected from 25 sand dunes across the region because it was not clear in the field whether formation of these sand dunes occurred at the same time or represented various depositional events. Both types of eolian sediments were processed for particle-size distribution.

### ***Recording Archaeological Sites***

Detailed and systematic recording of the archaeological record was not within the scope of this research project, as that has already been conducted for this region (Prates 2004). However, all archaeological sites observed during fieldwork were recorded briefly in order to assist future investigations. For each site, a GPS waypoint was recorded and a general description was noted. Some sites were also photographed. All diagnostic artifacts (lithics and ceramics) were noted and some were collected for future analysis. The presence of bone and fauna type was recorded as well as their degree of

preservation. All sites contained lithic artifacts except a few that were represented by concentrations of freshwater mollusk shells. Some sites included ceramics, grinding stones, lithic cores, saltwater shells, ñandú (a South American ostrich) eggshell fragments, charcoal, burnt bone, armadillo shell tiles, and gastropods. All were noted and basic field determination classified sites as potential domestic campsite or workshop sites based on the general composition of archaeological material, although such designations should be considered preliminary. In addition, the geological context relative to the landscape setting of each site was interpreted and recorded.

Field recording of the stratigraphy, geomorphology, and archaeological record during the first field season was completed when the region was sufficiently documented for constructing a generalized stratigraphic cross section of the valley, a representative collection of samples for radiocarbon and OSL dating was obtained, and the distribution of archaeological sites and geomorphologic features was sufficiently understood that they had become fairly predictable. Upon completion of field recording, a generalized stratigraphic cross section was drawn and the first set of radiocarbon samples was submitted to the NSF - Arizona Accelerator Mass Spectrometry (AMS) Laboratory (<http://www.physics.arizona.edu/ams/>). In addition, OSL samples were sent to the University of Illinois at Chicago Luminescence Dating Research Laboratory (LDRL) (<http://www.uic.edu/labs/ldrl/>) where they are currently in process, and sedimentological samples were submitted for particle size distribution to the Soil Characterization Laboratory at Texas A&M University (<http://soildata.tamu.edu/>).

## **CHAPTER IV**

### **LANDSCAPE HISTORY**

#### **Regional Pre-Quaternary Geological History**

The Middle Río Negro Valley is located within the Colorado Valley geological province (La Cuenca del Colorado) and is part of the Chacabonaerense Plain (Ramos 1999). Topographically, this region consists of plains and plateaus which rest on a fairly horizontal tabular plain (Suriano, et al. 1999). This area is located between the Ventania mountain range in the southeastern Pampas and the Somún Cura massif in northern Patagonia (ca. 50,000 km<sup>2</sup>) and 800-2000 m above sea level (Clapperton 1993). The geological province follows an extensive west-northeast fault line (Ramos 1999).

Underlying the valley is a Pre-Cretaceous crystalline-metamorphic bedrock, which is the deepest strata that has been investigated in detail for this region (Kaasschieter 1965, 1967; Zambrano 1972). Overlying this bedrock is the Pedro Luro formation (600-900 m) which consists of gypsiferous claystones that are slightly calcareous and likely dates to the Danian period. The next unit is the undated Elvira formation (57-135 m) which is made up of greenish-grey glauconitic sandstones intercalated with greenish clay and fine gravels. Table 9 summarizes the subsequent geological units that underlie the Middle Río Negro Valley.

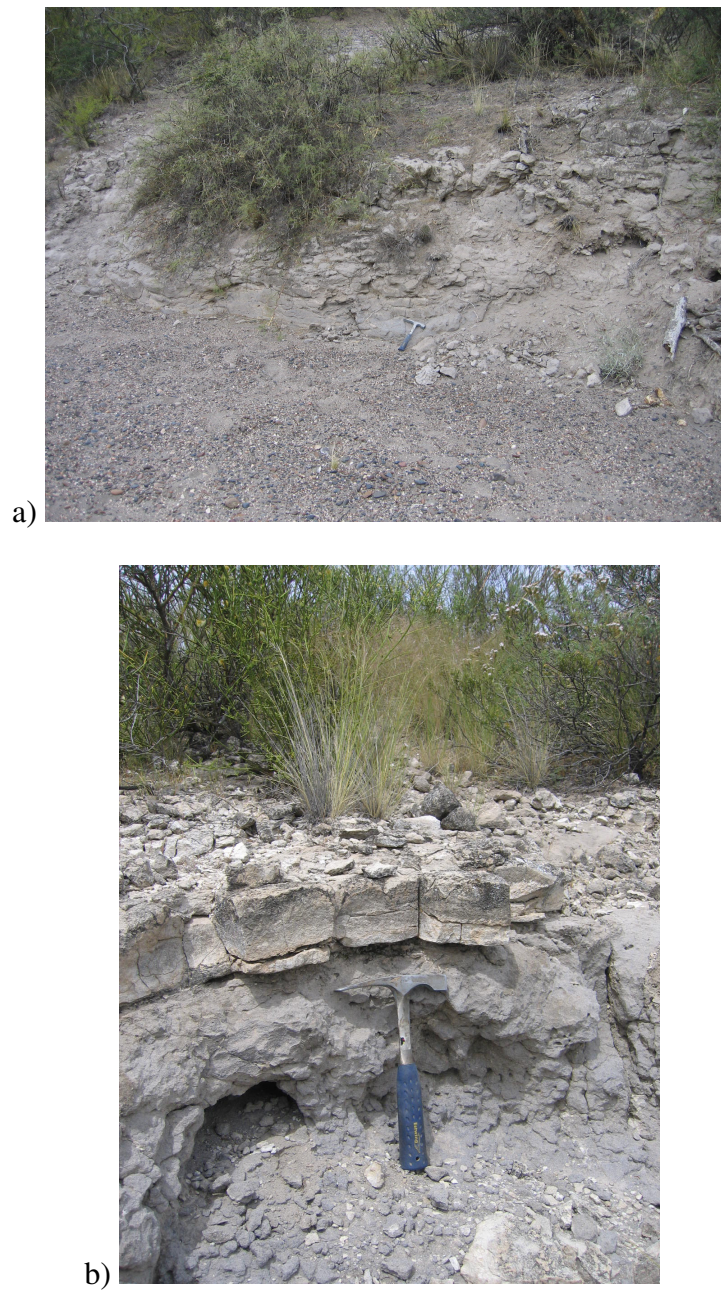
The El Barranca Final formation (361-528 m) was deposited during the Miocene based on microfossil evidence (Malumián, et al. 1998) and consists of sandstones with pelitic (silt-claystones) intercalations (Angulo, et al. 1979; Franchi 1977; Gelós, et al.

1992; Kaasschieter 1965; Malumián, et al. 1998; Suriano, et al. 1999) (Table 9). During the Pliocene, the Río Negro formation (180-212 m) was deposited, which is composed of medium to fine bluish-gray sandstones intercalated by siltstones and claystones (Figure 13) (Andreis 1965; Angulo, et al. 1979; Suriano, et al. 1999; Uliana 1979). In some

Table 9. Miocene-Holocene Geology.

	Strata	Age	Composition	Citation
QUATERNARY	Alluvial and eolian sediments within the valley		Alluvium: fine-coarse sands with gravel. Eolian sediments: medium-fine sand	
	Alluvial, colluvial, and eolian sediments in the basins on the modern plateau	Holocene	Basins: sands, silts, sparse fine gravel (alluvial-colluvial on basin slopes) and pelitic deposits, clayey-silts, and evaporates (basin bottoms)	(Suriano, et al. 1999)
	Alluvial and eolian sediments within the valley	Late Pleistocene?	5 levels (not defined in detail) including coarse sand, gravels and fine gravels	(Suriano, et al. 1999)
	<i>Plain is elevated:</i>			
	1) Initial incision of the modern Río Negro valley			
TERTIARY	2) formation of the basins across the plain (present meseta) (Suriano, et al. 1999)			
	Deposits of the Proto Río Negro: ancient alluvial plain and the <i>Rodados Patagónicos</i>	Early or Middle Pleistocene?	Sands and clasts with eolian polish; some locations consists of silty clay and/or a sandy mask over the gravels. Avulsion channel sediments are the same except for the proportions of fine gravel and the cementation by carbonate.	(Angulo, et al. 1979; Gonzalez Diaz and Malagnino 1984; Suriano, et al. 1999)
	<b>Río Negro Formation</b>	Pliocene	Medium-fine grained bluish-gray sandstone with sporadic intercalations of pinkish and cream siltstones and claystones. The sandstones have a volcanic matrix with plagioclase (labradorite and andesine), magnetite, hypersthene, hornblende, a little quartz, feldspar, and some heavy minerals and accessories.	(Andreis 1965; Angulo, et al. 1979; Suriano, et al. 1999; Uliana 1979)
	<i>Disconformity in some locations</i> (Angulo, et al. 1979; Kaasschieter 1965, 1967; Zambrano 1972)			
	<b>Barranca Final Formation</b>	Miocene	Sandstones with pelitic intercalations (clayey-silt) with microfossils in the pelitic levels.	(Angulo, et al. 1979; Franchi 1977; Gelós, et al. 1992; Kaasschieter 1965; Malumián, et al. 1998; Suriano, et al. 1999)





**Figure 13.** Outcrops of the Río Negro Formation (blue sandstone) found within the Middle Río Negro Valley. Locations a) and b) are ca. 70 km apart.

localities there is a unconformity between the Barranca Final and Río Negro formations (Kaasschieter 1965, 1967; Zambrano 1972), but in other zones a transitional boundary exists between the two units (Angulo, et al. 1979). Exposures of the Río Negro sandstone are common in the middle valley at the base of gullies and along portions of the plateau bank which are not covered by colluvium or eolian deposits. This unit forms the bedrock which directly underlies the alluvial deposits of the Río Negro.

### **Regional Quaternary Geological History**

From 30,000-14,000 BP, the regions that compose the headwaters of the Río Negro were extensively glaciated (Rabassa and Clapperton 1990). In addition, it is estimated that sea level was 120 m lower than today and that the Late Pleistocene delta was approximately 200 km offshore from the modern coast (Zárate and Blasi 1993). This is supported by analysis of Atlantic sea floor topography where rounded fluvial gravels were found in cores drilled into the continental shelf (Fray and Ewing 1964). Deglaciation in this region occurred between 14,000-13,000 BP (Clapperton 1990), which resulted in a significant influx of glacial-fluvial discharge in the Río Negro system (Zárate and Blasi 1993).

During the Pleistocene, possibly the Early to Middle Pleistocene, a proto Río Negro formed, depositing sediments on an alluvial plain (Angulo, et al. 1979; Gonzalez Diaz and Malagnino 1984; Suriano, et al. 1999). This proto-river was an extension of the Río Neuquén which preceded the formation of the Río Limay and was situated approximately 200 m above the modern valley floor (Gonzalez Diaz and Malagnino

1984). Overlying this alluvium is a deposit of the Patagonian Gravels (Rodados Patagónicos) which also appear to have a fluvial origin (Fidalgo 1999), although this issue still requires further investigation in order to clarify the origin and distribution of this unit. These gravels are composed of medium to fine volcanic rocks (andesite and basalt) with a sandy matrix, which is cemented by calcium carbonate in some locations. Although these gravels are only found in Patagonia, they differ between the northern and southern regions of Patagonia (Lapido and Pereyra 1999).

Following the formation of the proto Río Negro and deposition of Patagonian Gravels in the Pleistocene, the plateau underwent uplift. Tectonic uplift caused initial incision of the Río Negro Formation (Suriano, et al. 1999). Following initial erosion, the river began to deposit alluvial sediments as it served as a conduit draining water and carrying sediments from the Andean cordillera. During the same period, numerous large basins (bajos) formed across the plateau surface ranging from small basins of several kilometers in diameter to basins greater than 50 km<sup>2</sup> (Clapperton 1993; Methol 1967). The larger basins may have developed due to fault-guided subsidence whereas the smaller basins (less than 30 m deep) formed as a result of erosion in sparsely vegetated areas common in Northern Patagonia (Methol 1967).

### **Late Quaternary Geology of the Middle Río Negro Valley**

Within the boundaries of the modern Río Negro Valley lie both Pleistocene-Holocene sediments deposited by fluvial and eolian processes. Alluvial landforms



**Figure 14.** Alluvial terrace ( $T_1$ ) incised by the modern channel. Undercutting by the river exposes the fluvial gravels seen spilling out of the profile (lower portion of the photo).



a)



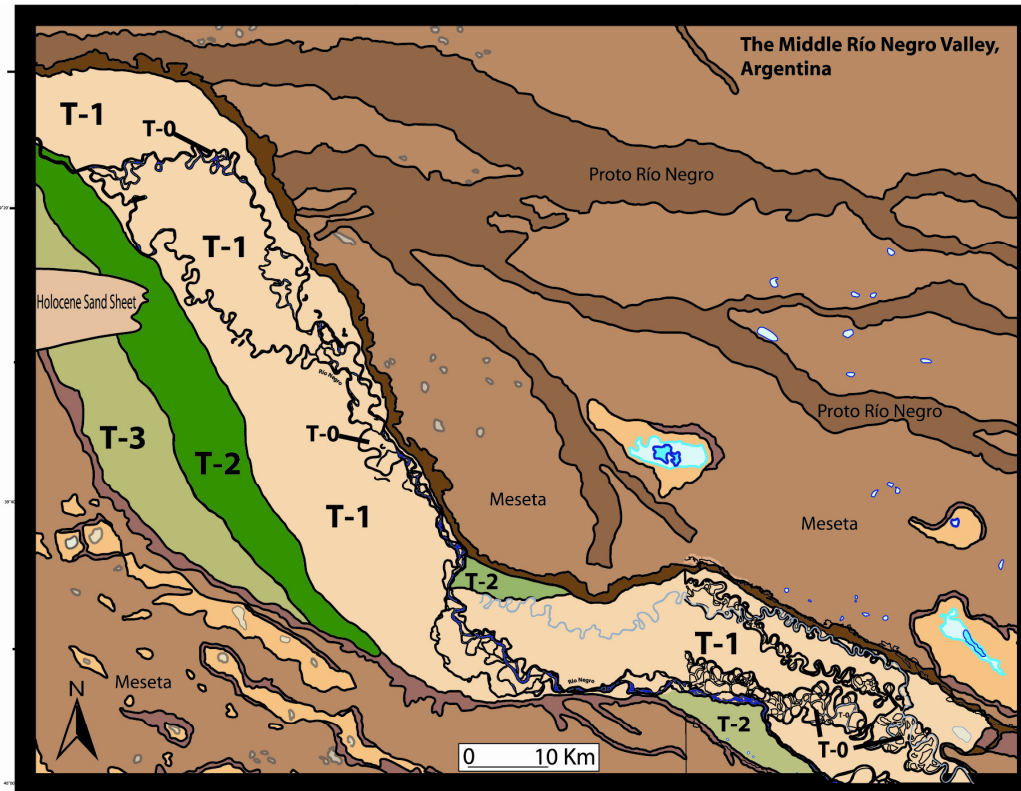
b)

**Figure 15.** a) Eolian blowout zone on surface of eolian mantle between avulsion channels 1 and 3 and b) sand dune complex (center of horizon) located between avulsion channels 1 and 2.

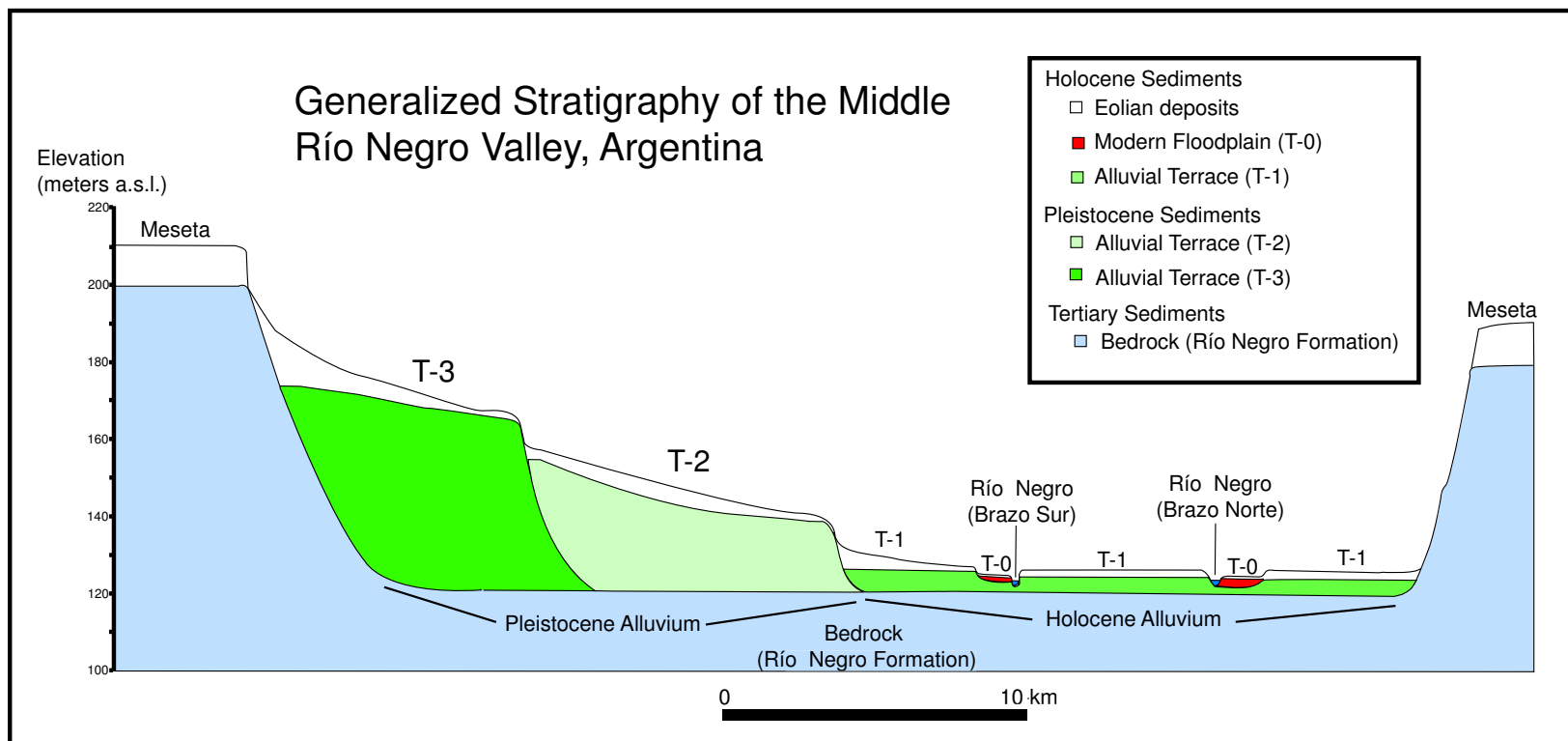
include terraces (Figure 14) and channel deposits. Eolian landforms consist of loess mantles, dune fields, and sporadic dunes (Figure 15). Uplift and valley incision occurred during the Middle to Late Pleistocene. As a result, the Río Negro downcut this valley and began to deposit alluvial sediments during the Late Pleistocene. This was accompanied by eolian deposition within the valley.

Alluvial terraces from the Late Pleistocene ( $T_3$  and  $T_2$ ) are still intact in some portions of the Río Negro Valley (Figure 16). Two terraces remain in the western portion of the study area and characterize this former fluvial regime (Figures 17 and 18) although they do not exist to the east of the study region to the coast. Very few remnants of these terraces are preserved to the west of this region as well. The most extensive and complete set of Pleistocene alluvial terraces lie along the southern margin of this valley in the western portion of the study region as well as in a small remnant in the southeastern area.

During the Pleistocene, the Río Negro drained an extensive network formed by numerous glacial valleys that extend between  $38^{\circ}45'$ - $41^{\circ}15'$  S latitude in the glacial system of the Patagonian Andes (Gonzalez Diaz and Malagnino 1984). This fluvial regime was much larger than the subsequent Holocene regime because the valley size is quite disproportionate in comparison to the modern fluvial system. Variations in the river system would have reflected fluctuations in glacial systems for rivers such as the Río Colorado to the north and the Río Negro (Zárate and Blasi 1993). This may explain why there are several Pleistocene terraces during this period reflect shifts in the fluvial regime as well.



**Figure 16.** Geomorphic map of the Middle Río Negro Valley. Pleistocene alluvial terraces are in the western portion (T<sub>3</sub> and T<sub>2</sub>) and the Holocene alluvial terraces (T<sub>1</sub> and T<sub>0</sub>) lie to the east of these deposits.



**Figure 17.** Generalized cross section of the Middle Río Negro Valley where Pleistocene alluvial terraces are preserved.

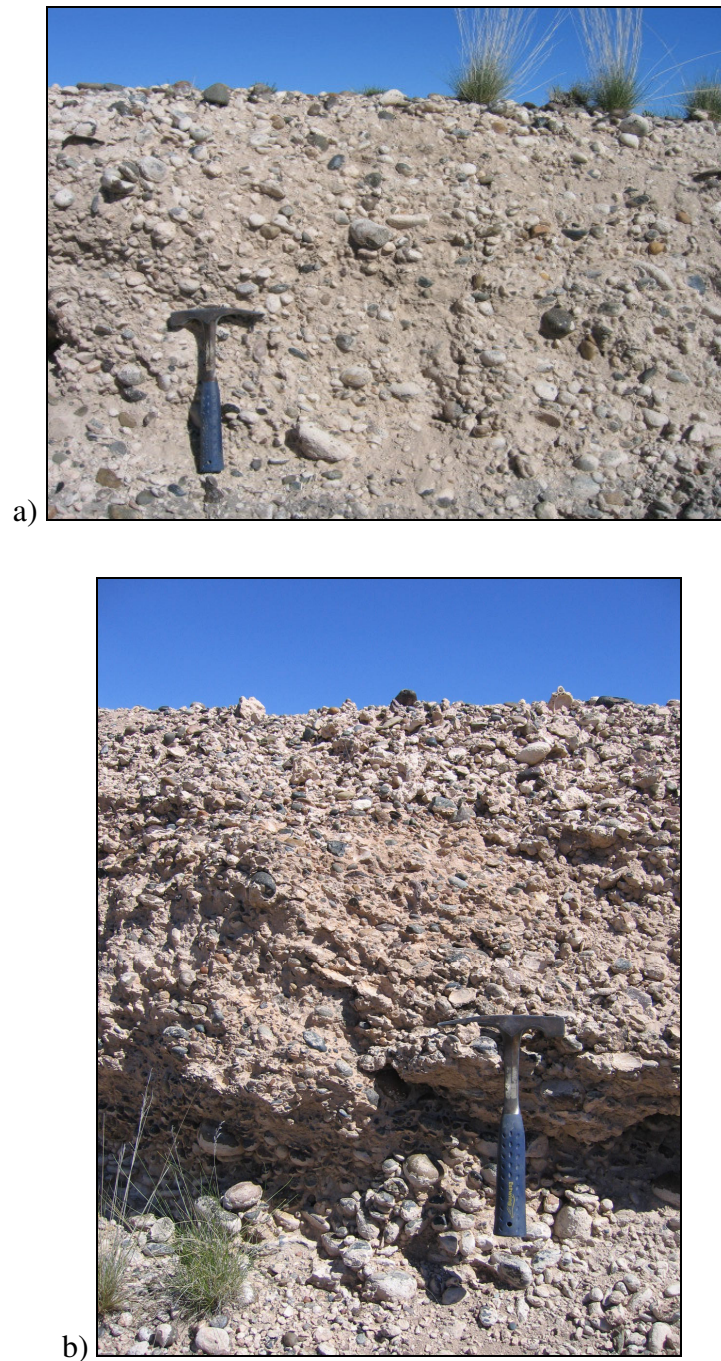




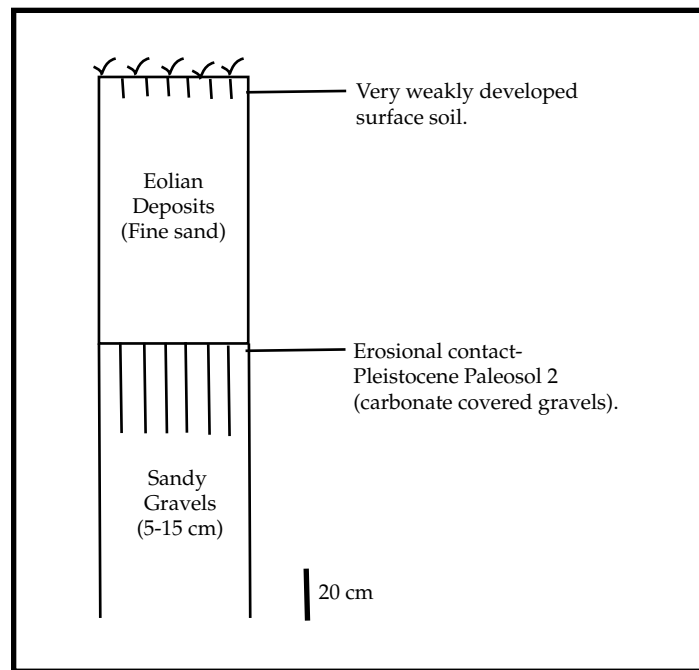
**Figure 18.** View of Pleistocene terraces looking cross-valley from the southern edge of the valley where road cuts across Late Pleistocene terraces nearly perpendicularly.

Each Pleistocene terrace ( $T_3$  and  $T_2$ ) composed primarily of gravel (gravel size is 5-15 cm) and in some places is capped with eolian sediments of varying thickness (ca. 0.5-2 m). The two terraces contain an eroded and buried paleosol that formed on a fining-upward sequence of fluvial sandy gravel deposits. A paleosol that formed on each deposit shows evidence of significant calcium carbonate accumulation upon the smaller gravels of the top of the deposit (Figure 19a and 19b). The strongest development is expressed in the upper portion of each profile. The main difference between  $T_3$  (Figure 19a) and  $T_2$  (Figure 19b) terraces is a difference in elevation due to incision and the degree of carbonate cementation of the sediments. The older terrace ( $T_3$ ) is more developed and classified as a Stage IV level of carbonate accumulation (Pleistocene paleosol 1) (Birkeland 1999). Carbonate accumulation decreases in  $T_2$  to a





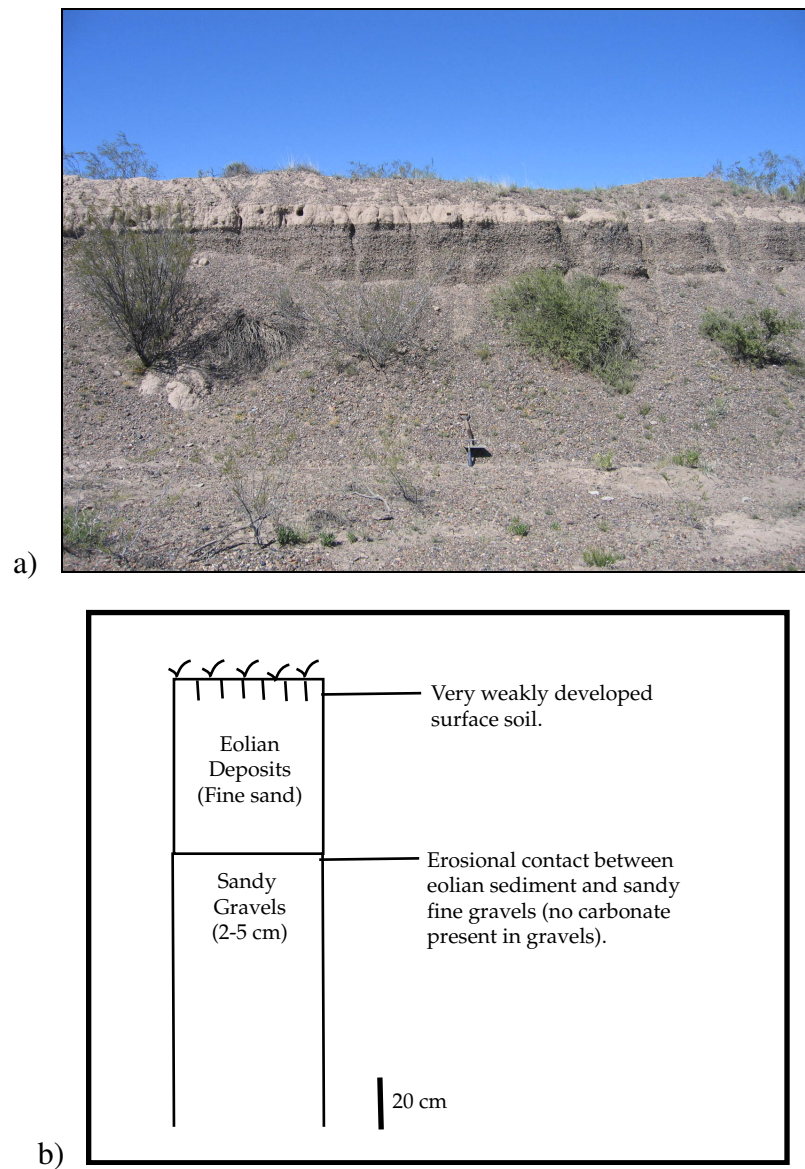
**Figure 19.** Both a) at S 39° 41.255,' W 65° 45.676' and b) at S 39° 26.625', W 65° 46.541' are profiles of the Pleistocene gravel terraces and illustrate the degree of calcium carbonate accumulation and cementation in these terraces.



**Figure 20.** Stratigraphy of Pleistocene Paleosol 2 underlying eolian deposition (S 39° 52.062, W 65° 26.277).

Stage III+ (Pleistocene paleosol 2) (Figure 20). Very little carbonate accumulation is evident in any of the subsequent Holocene deposits.

Following deglaciation, evidence suggests that this fluvial system changed from its previous regime in terms of discharge and sedimentation. Further incision of the valley occurred when the Río Negro began to downcut and erode the Pleistocene terrace deposits. As a result, the Río Negro deposited additional sandy gravel deposits ( $T_1$ ). These thick sandy gravel deposits contrast sharply with the Late Pleistocene gravel deposits by the fact that they contain little to no calcium carbonate and consist of finer gravels (Figure 21). For this region and for the valley as a whole,  $T_1$  is the most widely preserved and distributed alluvial deposit.



**Figure 21.** Early to Middle Holocene fine gravel terrace (S 39° 39.321', W 65° 29.261').  
a) Gravels extend down to shovel (center) but also deeper to bedrock; b) stratigraphy of fine gravel terrace.





**Figure 22.** Profile of the Early-Middle Holocene gravel terrace (S 39° 46.529', W 65° 24.558'). Dark sediment is coarse sand which is mixed with fine gravels with a very thin layer of eolian sediment (2-3 cm) preserved at the top of the profile.

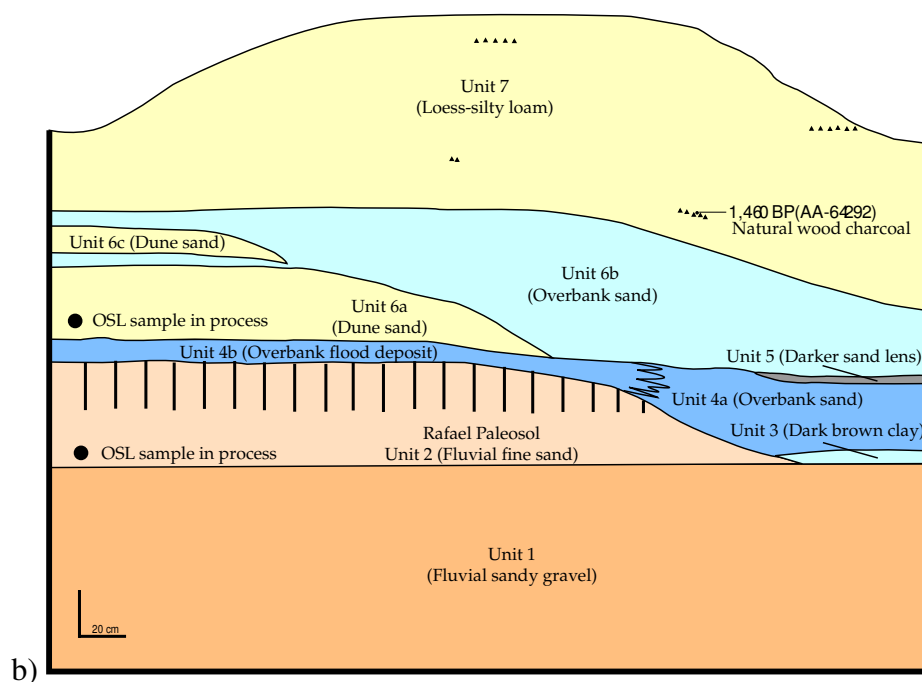
This Early to Middle Holocene fine gravel deposit was detected in numerous locations through the study area and recorded at 22 of these locations. The size, sorting, and general sedimentological characteristics of this unit are very consistent throughout the study area. The gravels are fine (2-5 cm) and mixed with coarse sand (Figure 22).

In general, these deposits are thick, ranging from 3-7 m, and in some areas bedding is evident. Very little upward fining is seen within these gravels and gravel size is fairly consistent. In most cases, this unit is separated by an erosional contact with overlying eolian loess deposits (Figure 23). In a few locations these deposits were



**Figure 23.** Clear erosional contact between the gravel terrace and overlying loess sediments.

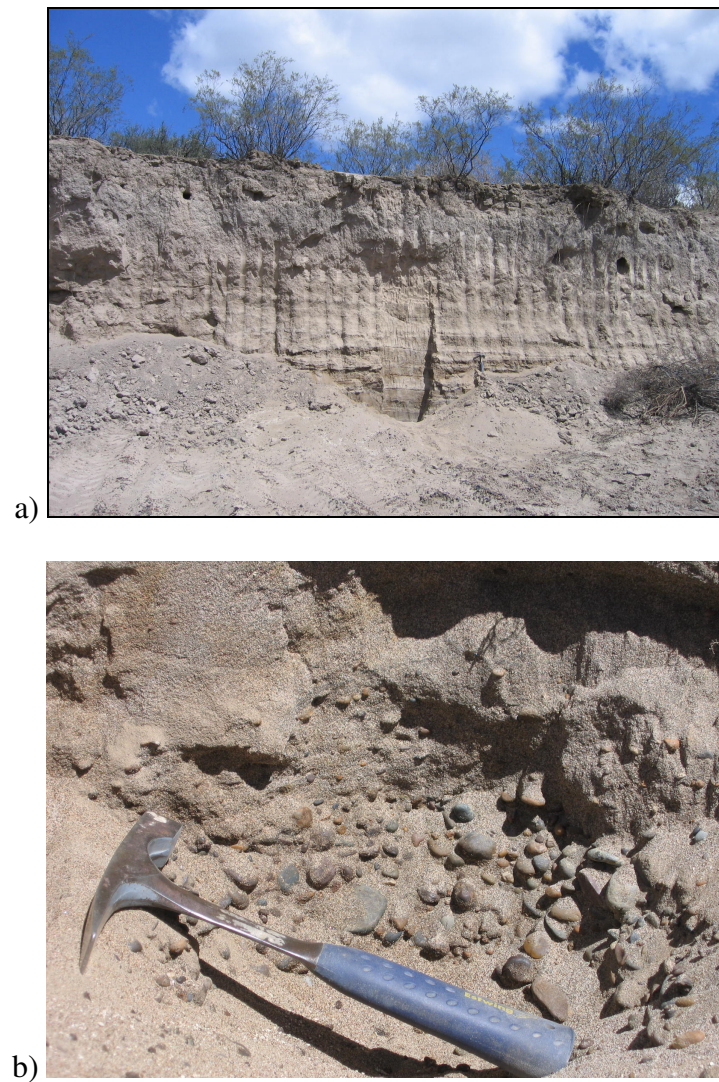
interfingered with sand units which were mineralogically very similar to the matrix sand within the gravels. In two locations, these gravel deposits were found with preserved fluvial sands overlying this unit. Location 1 (S 39° 48.197', W 64° 56.222'), was found in a gully cutting perpendicular to avulsion channel 2 (Figure 24). The sandy gravel deposit (Unit 1) was buried by 45 cm of fine sand (Unit 2) designated the Rafael Paleosol. This unit has clear evidence of weathering from the presence of strong redoximorphic features. Redox concentrations consisted of cemented nodules which were common (2-20% of the surface area), medium (2-5 cm) although a few were coarse (5-20 cm), distinct to prominent, spherical in shape, and mostly located towards the top of the unit but extended downwards and decreased with depth. Overlying this unit was a



**Figure 24.** a) Gully cutting perpendicular to an abandoned channel of the Río Negro (S 39° 48.197, W 64° 56.222). Profile in Figure 20 was taken from the exposure on the left side of the photo where the tape measure is placed in the lower pit. b) Stratigraphic profile at Location 1. Unit 2 is designated the Rafael Paleosol. Note location of two OSL samples currently in process for dating the initial deposition of these units.

sequence of 1.5 m of alluvial and eolian deposits. The overbank sediments of the avulsion channel and dune deposits appear to have been deposited contemporaneously. This sequence was covered by a mantle of loess sediments (silty loam). The second location where fluvial sands overly the Early-Middle Holocene sandy gravel deposit was found ca. 40 km to the east (S 40° 01.211' W 64° 34.486') along a steep cut bank of a former channel of the Río Negro (Figure 25). Unit 1 (Figure 26) is a sandy gravel of coarse sands and fine gravels (1-5 cm). Overlying this unit is Unit 2 which consists of a fine sand with a texture very similar to Unit 2 found at Location 1 (Table 10). The total sand percentage ranges from 95.2-97.8%, silt ranges from 1.8-4.2%, and clay from 0.4-0.6%. The main difference between these two samples is the slight differences in medium and fine sand content, but this could be attributed to lateral variation between these two locations which are 40 km apart, and is not considered to be significant. Unit 2 also contains similar redoximorphic features as Unit 2 at Location 1. Redox concentrations were common, medium to coarse, distinct to prominent throughout this unit. These units are also buried by a sequence of fluvial and eolian deposits (Units 3-8). Unit 8 is the loess unit (loam) which is found throughout the region and is also similar in texture to the loess deposited at Location 1 (Table 11), although it is a thinner deposit due to erosion. The percentage of very fine sand, fine silt, and total clay are fairly close between these two sediments. Differences between these locations can also be accounted for by spatial variation, deposit thickness, and erosional processes which may skew the sorting of the deposits, particularly the thinner deposit at Location 2. This unit has been correlated with the Rafael paleosol and OSL samples for dating are in process.

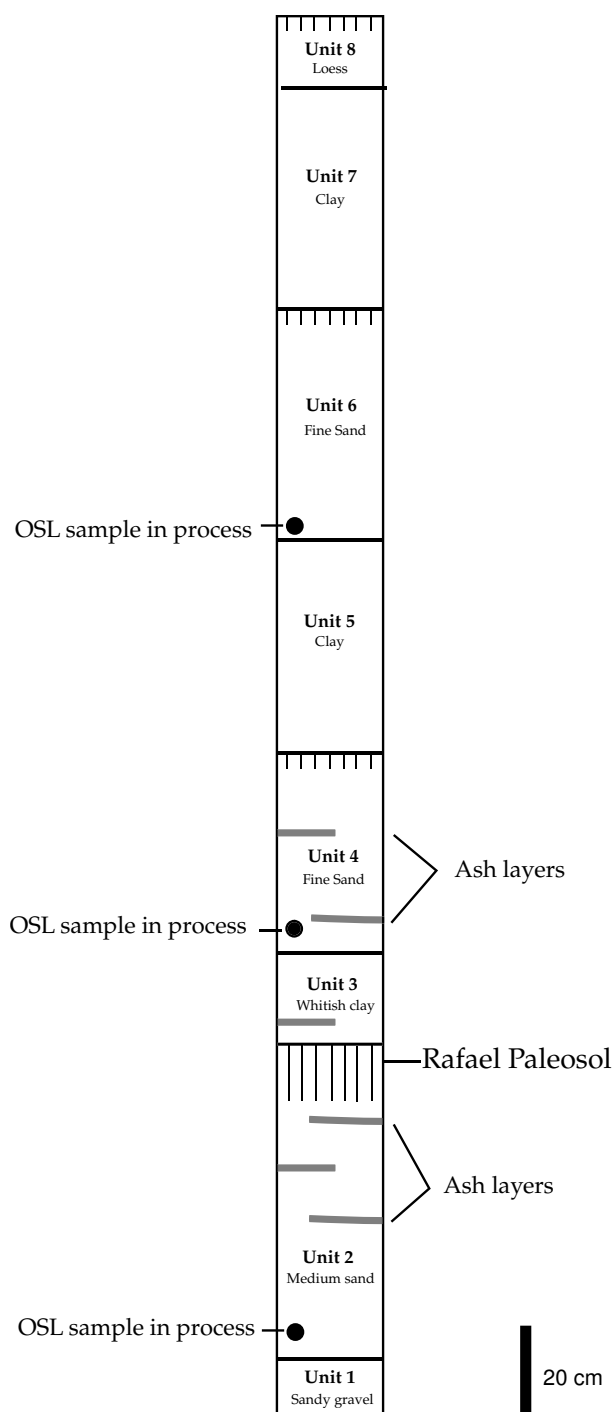




**Figure 25.** a) Location 2 where fluvial sand was found preserved overlying sandy gravel deposit and b) sandy gravel unit (Unit 1) at base of profile.

The Rafael paleosol is considered a marker horizon of the Early to Middle Holocene alluvial deposit. Where the paleosol is not preserved but the coarse sand-fine gravel units is present, this is also considered a marker horizon for the Early to Middle Holocene deposit.





**Figure 26.** Stratigraphic profile of second location with fluvial sediment overlying sandy gravel deposit at Location 2.

Table 10. Sedimentology of Fluvial Sand Overlying the Sandy Gravel at Location 1 and Location 2.

Sediment Size Class	Location 1 (%)	Location 2 (%)
Very coarse sand	0	0
Coarse sand	0	0.7
Medium sand	1.5	20.2
Fine sand	84.6	60.7
Very fine sand	11.7	13.6
TOTAL SAND	97.8	95.2
Fine silt	0.7	1.7
TOTAL SILT	1.8	4.2
Fine clay	0	0
TOTAL CLAY	0.4	0.6
Sediment Texture	Fine sand	Fine sand

Table 11. Sedimentology of Eolian Loess Overlying the Sandy Gravel at Location 1 and Location 2.

Sediment Size Class	Location 1 (%)	Location 2 (%)
Very coarse sand	0.1	0
Coarse sand	0.1	0.1
Medium sand	0.1	1.1
Fine sand	3.6	13.3
Very fine sand	29.5	36.0
TOTAL SAND	33.4	50.5
Fine silt	24.4	18.1
TOTAL SILT	60.9	39.7
Fine clay	0	0.2
TOTAL CLAY	5.7	9.8
Sediment Texture	Silty loam	Loam

Altogether, these characteristics suggest that this Early to Middle Holocene fluvial regimen may have been a braided stream regime rather than the meandering

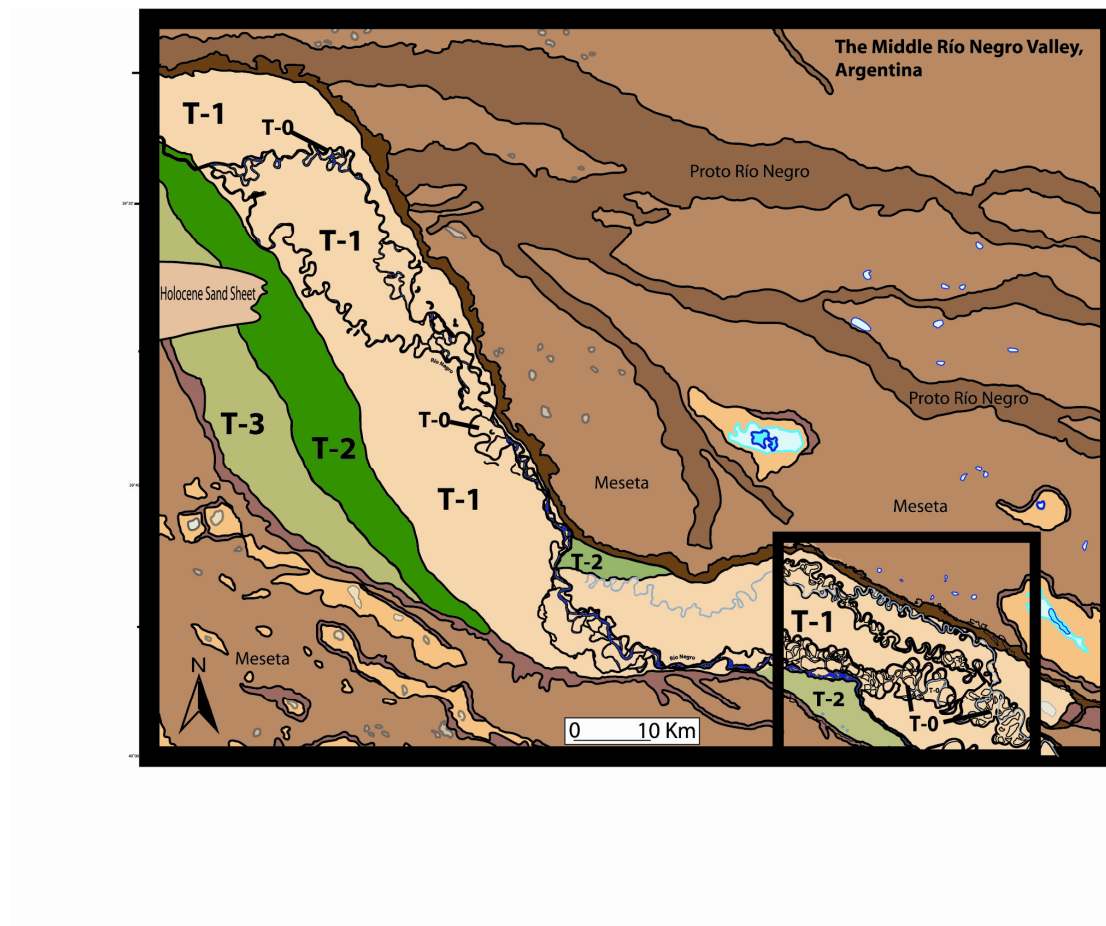
regime of the modern river for several reasons. The thick gravel deposits which were recorded in the field could be interpreted as the aggraded deposits of a meandering river. Moreover, other characteristics appear to indicate that this is a braided deposit. There are sand lenses and interfingering sand deposits which could represent the islands and bars that formed within the channel of a braided river. The thick deposits of sandy gravel could indicate a high percentage of bedload material, which is typical for braided streams. The sandstone bedrock of this valley is friable and erodes easily, which is another characteristic of braided regimes. In addition, the slope of this valley is significant enough to support a braided regime as was present during the Pleistocene. This would then indicate that the Río Negro was a braided river until the regime shifted in the Middle Holocene or Early Late Holocene.

### **Late Holocene Landscape History**

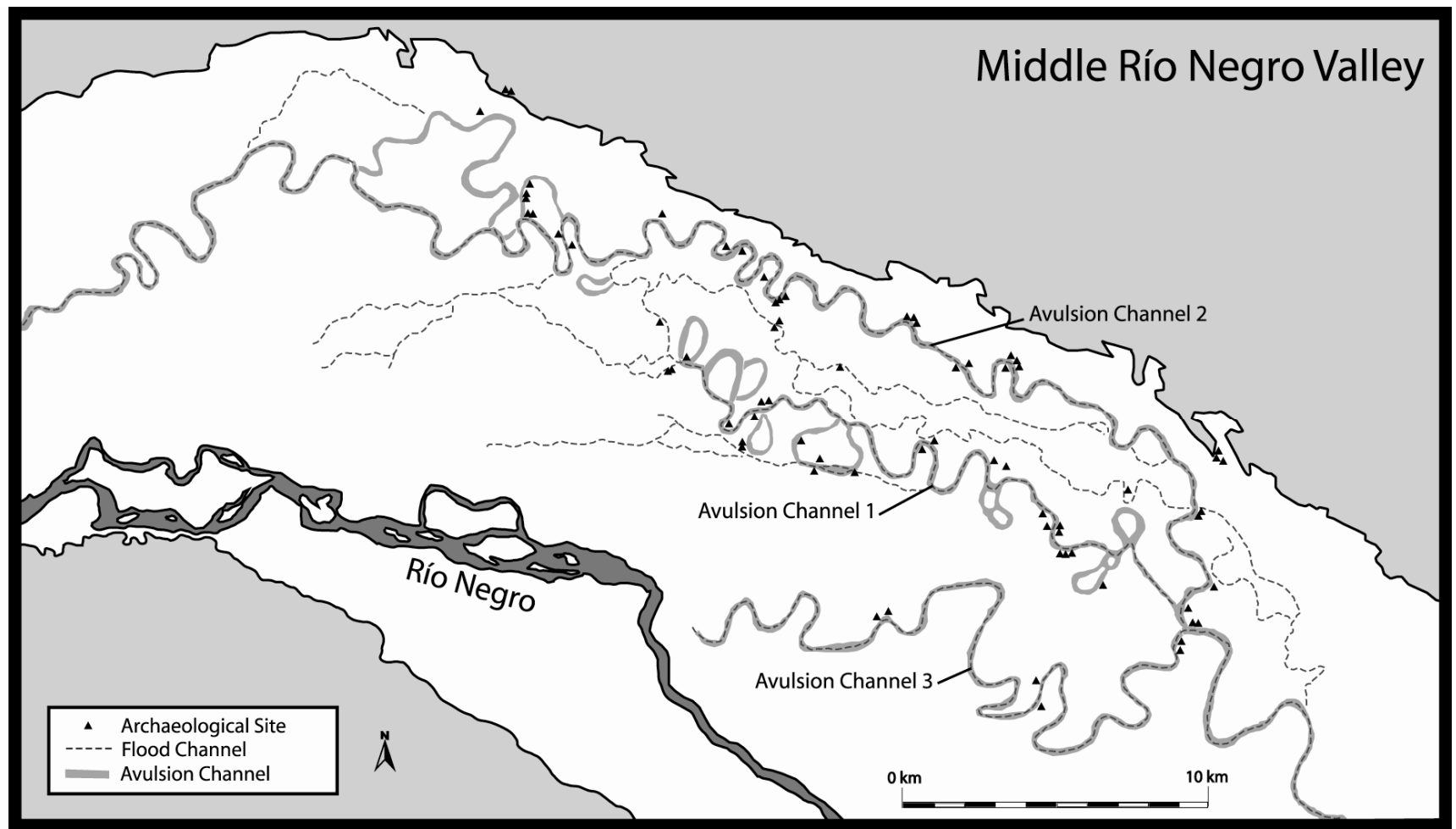
Based on evidence from geomorphology, stratigraphy, and radiocarbon chronology, a segment of this river in the middle valley underwent avulsion on three occasions during the Late Holocene (Figure 27). As a result, three large abandoned avulsion channels presently cross this landscape in this area (Figures 28, 29, and 30).

#### ***Definition of Channel Avulsion***

The original definition of a channel avulsion which is most commonly cited is “the sudden abandonment of a part or the whole of a meander belt by a stream for some new course at a lower level on the floodplain (Allen 1965).” However, it is necessary to



**Figure 27.** Location of the channel avulsions in the eastern portion of the study area (inside black box).



**Figure 28.** Map of the three avulsion channels in the eastern portion of the study region.



**Figure 29.** Avulsion Channel 2. Truck is located in the center of the channel bed which has been infilled with eolian sediments since abandonment.



**Figure 30.** Avulsion Channel 1 as it appears in the present landscape.

update this definition due to recent investigations into channel avulsion of rivers worldwide. First, avulsion can be sudden or gradual (Slingerland and Smith 2004). In some cases, avulsion can occur virtually overnight and in other cases, a river may form channel networks and avulsion could take up several centuries to complete (Knighton and Nanson 1993; Makaske 2001; Nanson and Huang 1999; Smith and Smith 1980; Smith, et al. 1989). It has been estimated that avulsion on the Meuse-Rhine delta in the Netherlands sometimes takes up to 1,250 years to complete (Stouthamer and Berendsen 2001). Second, recent investigations indicate that channel avulsion is not limited to meandering streams as described above but has also been recorded in braided rivers on alluvial fans, braided river floodplains, meandering river floodplains, and deltaic plains (Makaske 2001). Third, although slope is an important factor in channel avulsion, recent studies suggest that this is not the only factor in the avulsion process and sometimes it is not involved. Other factors included regional causes (e.g., climate change, tectonics) and other local factors (e.g., flooding, sedimentology, variations in aggradation, vegetation, and chute cutoff). Therefore, an updated definition for avulsion has been proposed as “the process by which flow is diverted out of an established river channel into a new course on the adjacent floodplain” or from its “parent channel” to its “avulsion channel” (Slingerland and Smith 2004). Channel avulsion occurs where space allows for channel relocation such as in wide valleys, alluvial fans, alluvial plains, and deltas (Jones and Schumm 1999).

A recent review classifies channel avulsion into several categories (Slingerland and Smith 2004). If all flow is diverted from the parent channel to the avulsion channel,

this is a full avulsion. Otherwise, a partial avulsion occurs whereas water continues to flow in the parent channel while some of the flow is diverted to the avulsion channel. This creates an anastomosing channel if the coexisting channels rejoin downstream or forms a distributary system if they do not rejoin. In addition, sequential avulsions can occur around the same segment of a river channel (nodal avulsions) or randomly along its length (random avulsions). Small-scale avulsions are termed local avulsions and large-scale avulsions are known as regional avulsions. There are three styles of river avulsion: 1) avulsion by annexation (avulsion into an existing channel), 2) avulsion by incision (creation of a new avulsion channel cutting into the floodplain), and 3) avulsion by progradation (extensive deposition through distributary channels). As mentioned above, the rate for a channel to shift its course can occur abruptly or gradually, e.g., 1 day for the Yellow River in China (Ning 1990) to several centuries. A number of studies modeling avulsion have attempted to predict avulsion frequency in river channels although much variability in avulsion frequency has been observed in fluvial systems throughout the world e.g., from 28 to 1400 years (Stouthamer and Berendsen 2001).

### ***Pre-Conditions for Avulsion***

A number of events can increase channel instability and cause a channel to draw closer to avulsion threshold: increase in sinuosity (Schumm, et al. 1996), delta growth, base-level fall, tectonic uplift, natural levee-alluvial ridge growth, alluvial fan growth, hydrological change in flood peak discharge, sediment influx, blockage by vegetation, log jams, and ice jams (Ethridge, et al. 1999; Harwood and Brown 1993; King and



Martini 1984; McCarthy, et al. 1992; Schumann 1989), animal trails, and capture (see Table 1 in Jones and Schumm 1999 and detailed reviews in Makaske 2001 and Aslan et al. 2005). Several of these events may also act as triggers for avulsion: tectonic uplift, hydrological change in flood peak discharge, sediment influx, log jams, and ice jams (Jones and Schumm 1999).

A channel avulsion is essentially a crevasse channel which does not heal but continues to receive discharge from the main channel. If the channel enlarges and all discharge is diverted into this channel, this is full avulsion and the avulsion process is complete. So why do some crevasse channels heal over time and why do others undergo avulsion? Slingerland and Smith (2004) suggest that this is related to the style of avulsion, area and configuration of the invaded flood basin, and basin surface including its topography, water-table elevation, vegetative cover, resistance to erosion, and whether pre-existing channels are present. They condense these factors into several parameters for analyzing bifurcating channels in order to build a theoretical model to understand the avulsion process. A channel and its two bifurcated channels will be stable if the sediment received by the bifurcated channels is in balance with their sediment carrying capacity. Otherwise, erosion or deposition will occur until they are stabilized or one of the channels heals. According to Slingerland and Smith (2004), channel avulsion occurs due to the following: 1) sediment partitioning between the two bifurcated channels from the main channel, and 2) whether the two bifurcated channels to adjust their capacities.

This discussion by Slingerland and Smith (2004) is unique because it focuses in on the intrinsic or local factors that are the underlying precondition for channel avulsion compared to a number of studies which focus more on external factors or only trigger events as an explanation for avulsion. As mentioned above, a bifurcated channel will be stable if sediment received by the two split channels is in balance with their sediment carrying capacities. When this changes, the channel is not stable, and as this imbalance increases, this develops into the conditions necessary for full channel avulsion (Slingerland and Smith 2004). An increase in aggradation in the main channel is commonly cited as a pre-condition for avulsion and has been linked to a higher avulsion frequency. An increase in aggradation can be caused by several factors including increase in sediment load that exceeds carrying capacity of the channel, changes in peak water discharge, and decrease in channel gradient caused by an increase in sinuosity, extension of a delta, fall of base-level to a shallower slope, uplift downstream, or rise in base level.

In general, it has been proposed that channel avulsion can not occur unless there is rapid alluviation in the main channel, there is a wide unobstructed floodplain, and the system experiences frequent floods of high magnitude (Slingerland and Smith 2004). Although a wide floodplain is clearly necessary for the avulsed channel to relocate its position, the necessity for rapid alluviation and high magnitude flooding has yet to fall under general consensus among geomorphologists. For example, according to Jones and Schumm 1999, an unstable channel which is close to avulsion threshold could cross that threshold due to a small magnitude flood and would avulse. In addition, although

gradient advantage of a channel above its floodplain logically is a reliable precondition for channel avulsion and although avulsion is commonly attributed to gradient advantage, there are other conditions where channel elevation may not be the main precondition for an avulsion. For example, other studies suggest non-gradient related preconditions that pre-dispose a channel for avulsion. For example, a recent study of the Mississippi River proposed that the sandy substrate of this river valley and distribution of floodplain channels are considered more important to Late Holocene river avulsion than gradient advantages (Aslan, et al. 2005). The sandy substrate of this river facilitates erosional scour of avulsion channels and the availability of floodplain channels for occupation by parent channel flow also facilitates avulsion as well. According to Aslan et al. 2005, all channel avulsions undergo two phases prior to avulsion regardless of the type of pre-condition or trigger event: 1) pre-conditions for an avulsion (as discussed above) or avulsion threshold (Jones and Schumm 1999) and 2) a trigger event (Mohrig, et al. 2000).

### ***Triggers of Avulsion***

Over the last 25 years, numerous studies have proposed a wide variety of causes or triggers for channel avulsion. At this point, it does not appear that we know the exact cause of channel avulsion for all situations and fluvial environments (Aslan, et al. 2005; Slingerland and Smith 2004). However, most studies indicate that a river channel will not undergo avulsion until its channel instability has approached avulsion threshold closely enough so that a trigger event can cause it to cross that threshold resulting in

avulsion of the channel (Jones and Schumm 1999). For example, a comparatively stable channel that experiences a large or small flood will not likely cross avulsion threshold (Figure 2 in Jones and Schumm 1999). Likewise, an unstable channel may undergo even a small flood but due to its proximity to avulsion threshold, will cross that threshold and avulse. A large flood will not necessary carry a river over this threshold (Brizga and Finlayson 1990; Ethridge, et al. 1999). Therefore, according to Jones and Schumm (1999), flood size is not the determining factor or necessary trigger event in avulsion. The higher degree of channel instability which draws a channel closer to avulsion threshold combined with flooding, will increase the probability for channel avulsion.

As opinions vary about the necessary preconditions for a channel avulsion, so do they vary about the type of trigger event is necessary to cross the avulsion threshold. In general, many studies claim that flooding is the most common event that triggers avulsion. However, because there is such variability and combination of preconditions suggested for pre-avulsion channels, trigger events also seem to vary and the definitive pre-condition and trigger event for channel avulsion has yet to be fully resolved. It is likely that these factors strongly depend on the individual characteristics of each fluvial system and that pre-conditions and trigger events will vary as widely as these systems do from one another.

On a final note, one concept that could be involved in the consideration of this complex process of channel avulsion is that of a geomorphic threshold (Schumm 1973). Schumm (1973) presented this concept as an alternative to defining change in a fluvial

system due to traditional explanations citing climate change and tectonics (extrinsic thresholds). He stated that “Simplification and the search for order in simplicity caused intrinsic thresholds to be overlooked in preference to explanations based on external controls (p. 309).” The geomorphic threshold which is an intrinsic threshold develops within a fluvial system over time. Geomorphic thresholds are difficult to differentiate from extrinsic thresholds. However, according to Schumm (1973): “...when a change of slope is involved, the control is geomorphic, and the changes whereby the threshold is achieved is intrinsic to the system (p. 301).” This concept is carried over into the concept of an avulsion threshold (Jones and Schumm 1999). In Table 1, Jones and Schumm (1999) list processes and events that pre-dispose a channel to avulsion or draw the channel closer to avulsion threshold and events that can act as triggers to avulsion. There is an emphasis on changes in slope between the main channel and the slope of a potential avulsion course as well as sediment carrying capacity of the main channel. I think that it is clear that they are referring to a geomorphic threshold as described in Schumm (1973). I find the concept of an avulsion threshold presented by Jones and Schumm (1999) the strongest explanation as to why channels undergo avulsion.

### ***Channel Avulsion in the Middle Río Negro Valley***

Each channel avulsion appears to be a full avulsion where the parent channel flow was completely diverted into the new avulsion channel based on the dimensions of each avulsion channel. Of the three avulsion events, although all three occurred within the Middle Río Negro Valley, the first two were nodal avulsions and the last avulsion

was a random avulsion slightly downstream. Since the valley narrows at the downstream boundary of the study region, the avulsion channels rejoin a common parent channel which flowed through this region throughout the Late Holocene. Therefore, these avulsions were local avulsions. Based on the geomorphology and stratigraphy, each avulsion was by incision.

### ***Stratigraphy and Dating of Avulsion Channels 1-3***

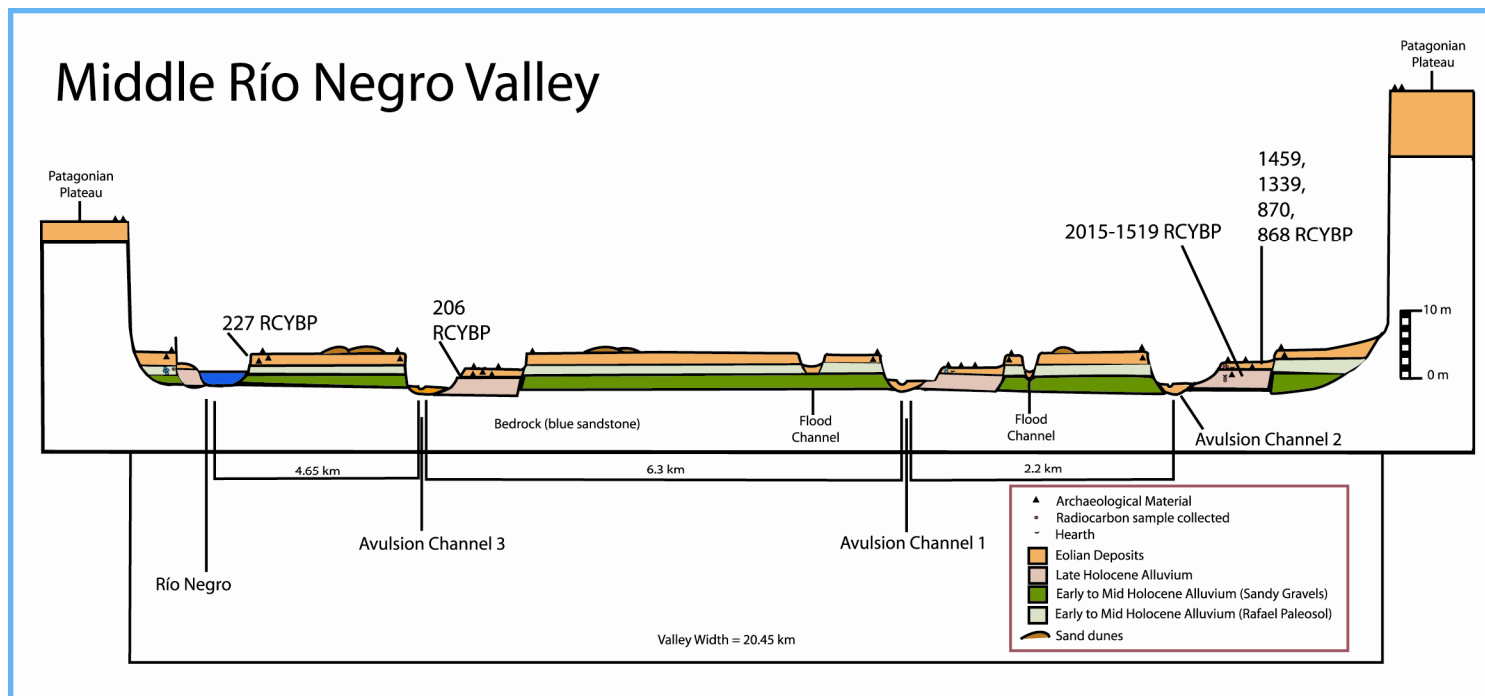
In the Middle Río Negro Valley, three avulsion channels were identified on aerial photographs and through field study. Radiocarbon dating has been conducted on stratified samples from Avulsion Channels 2, 3, and the modern river channel (Table 12). Chronologically, the three channels are ranked from earliest (Avulsion Channel 1) to most recent (Avulsion Channel 3) and Avulsion Channel 2 was occupied by the principal channel during the intervening period (Figure 31). This order is supported by radiocarbon dating and additional chronology will be provided by OSL dating once samples have been processed.

As indicated in Figure 31 and Table 12, samples for radiocarbon dating of Avulsion Channel 2 were widely available compared to Avulsion Channels 1 and 3. No organic material was found along Avulsion Channel 1 for dating and only 1 sample was found along Avulsion Channel 3 and the modern channel. Therefore, the dating of Avulsion Channel 2 is comparatively more comprehensive.

Table 12<sup>1</sup>. Radiocarbon Ages from the Middle Río Negro Valley.

Sample #	GPS Location	WP	Unit	#	Depth (cm)	14C age (yr BP)	Calendar years (one sigma)	Material	Context	Interpretation
AA	S39° 46.146'						BC 32-31			
64294	W64° 57.379'	284	A3	2	59	2,015±38	BC 20-12	wood charcoal	From hearth at San Carlos site buried by	Contemporary to AC2
AA	S39° 49.574'						BC 1- AD 82	wood charcoal	Hearth at site buried by fluvial sediments.	
64288	W64° 50.516'	380	A4	3	10	1,519±50	AD 562-643	wood charcoal	Dispersed charcoal	Contemporary to AC2
AA	S39° 49.594'					TBD				
67949	W64° 50.493'	379		1		(submitted)		bulk sample		Shell line on AC2
AA	S39° 48.197'							wood charcoal	Charcoal from 498 site at base of eolian mantle	
64292	W64° 56.222'	498	C1	3	77	1,459±41	AD 609-660	wood charcoal	From burnt feature on point bar of AC2	Contemporary to AC2
AA	S39° 50.724'							wood charcoal		
64290	W64° 44.947'	315	A3	2	4	1,339±48	AD 673-772	wood charcoal	La Victoria skeleton 1	Contemporary to AC2
AA	S39° 49.418'									
62796	W64° 50.069'	-		5		868±48	AD 1182-1266	bone		Eolian sediments near AC2
AA	S39° 50.648'						AD 1182-1233	wood charcoal	Charcoal from 284 site; base of loess mantle.	
64293	W64° 45.012'	375	B1	5	18	870±39	AD 1245-1264	wood charcoal		Alluvial sediments of AC2
AA	S39° 57.178'						AD 1651-1681	wood charcoal	Cutbank of modern channel near La Costa.	
64289	W64° 51.726'	469	A3	13	170	227±40	AD 1731-1802	wood charcoal		Alluvial sediments of modern channel
							AD 1658-1698		Cutbank of Avulsion Cannel 3 on Brussino ranch.	
							AD 1723-1808			
							AD 1839-1843			
AA	S39° 56.365'						AD 1869-1877	wood charcoal		Contemporary with AC3
64291	W64° 45.612'	356	B1	2	47	206±40	AD 1946-1950	wood charcoal		

<sup>1</sup> Calibration data set: shcal04.14c; # McCormac et al. 2004; CALIB RADIOCARBON CALIBRATION PROGRAM\*; Copyright 1986-2005 M Stuiver and PJ Reimer; \*To be used in conjunction with: Stuiver, M., and Reimer, P.J., 1993, Radiocarbon, 35, 215-230.

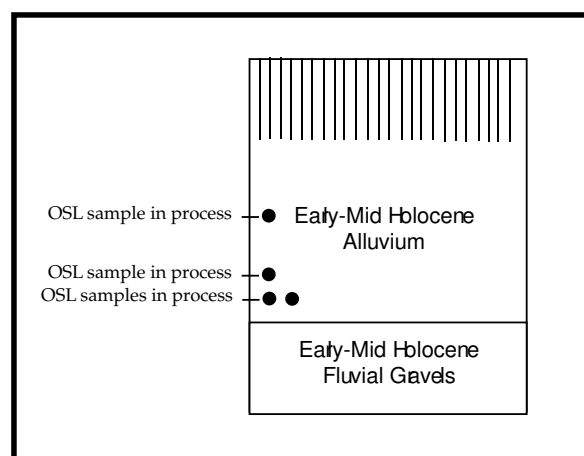


**Figure 31.** Generalized stratigraphic cross section of the Middle Río Negro Valley showing the three avulsion channels.



### ***Chronology of Avulsion Channel 1***

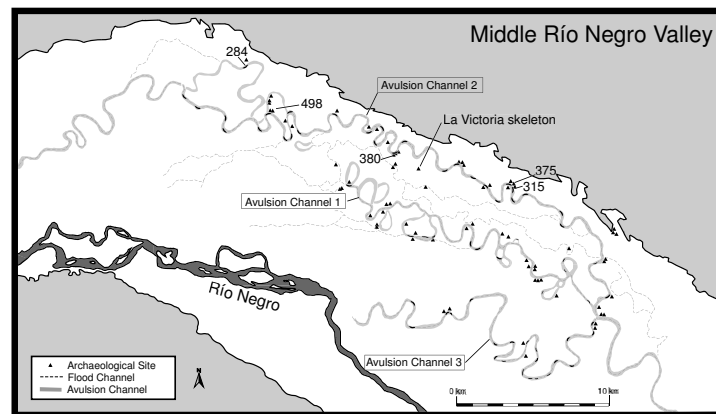
Avulsion Channel 1 has not been dated although it is assigned to the period before Avulsion Channel 2 and after the period when the Early-Middle Holocene fine sandy gravel was deposited. The OSL samples on these deposits may bracket this avulsion channel more definitively (Figure 32). Additional OSL samples from this avulsion channel would also aid in dating this channel.



**Figure 32.** Composite section of Early-Mid Holocene fluvial sediments and locations of OSL samples currently in process.

### ***Chronology of Avulsion Channel 2***

Radiocarbon samples from six locations along Avulsion Channel 2 were dated (Table 12 and Figure 33). Five of the samples were wood charcoal from archaeological sites and one sample was processed on bone from a human burial (the La Victoria skeleton). Radiocarbon dating was productive for defining the chronology of the alluvial



**Figure 33.** Profiles along Avulsion Channel 2 where radiocarbon samples were collected and dated.

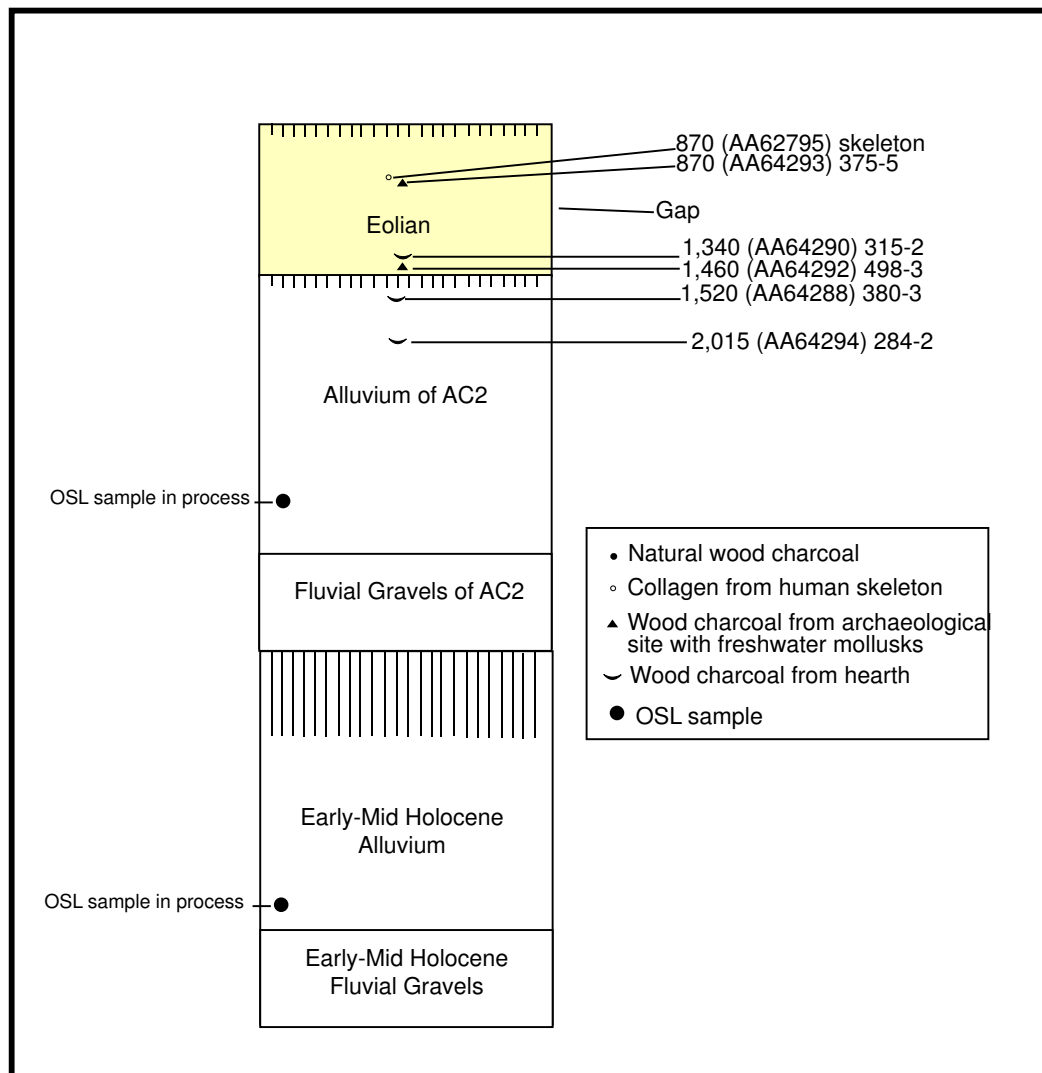
and eolian sediments found along Avulsion Channel 2 (Figure 34). One OSL sample in process may indicate when deposition of the alluvial sediments or the initial avulsion which formed Avulsion Channel 2 occurred.

### ***Chronology of Avulsion Channel 3***

Avulsion Channel 3 was dated due to its geomorphic relationship to Avulsion Channels 1 and 2 (i.e., that it is the most recent avulsion channel) and one radiocarbon age. This sample was taken from a profile along the edge of Avulsion Channel 3 from an overbank deposit (Figure 35).

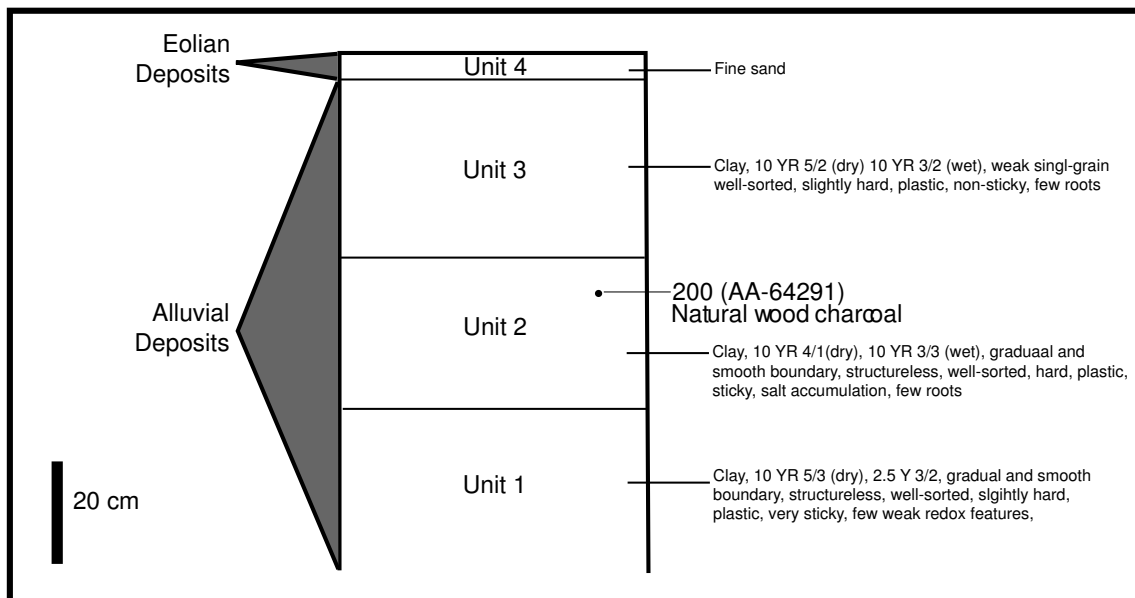
### ***Chronology of the Three Avulsion Channels***

Based on evidence from the geomorphology, stratigraphy, and radiocarbon dating of samples from Avulsion Channels 2 and 3 in addition to the modern channel, it



**Figure 34.** Composite section of the stratigraphy representing alluvial and eolian deposits along Avulsion Channel 2.

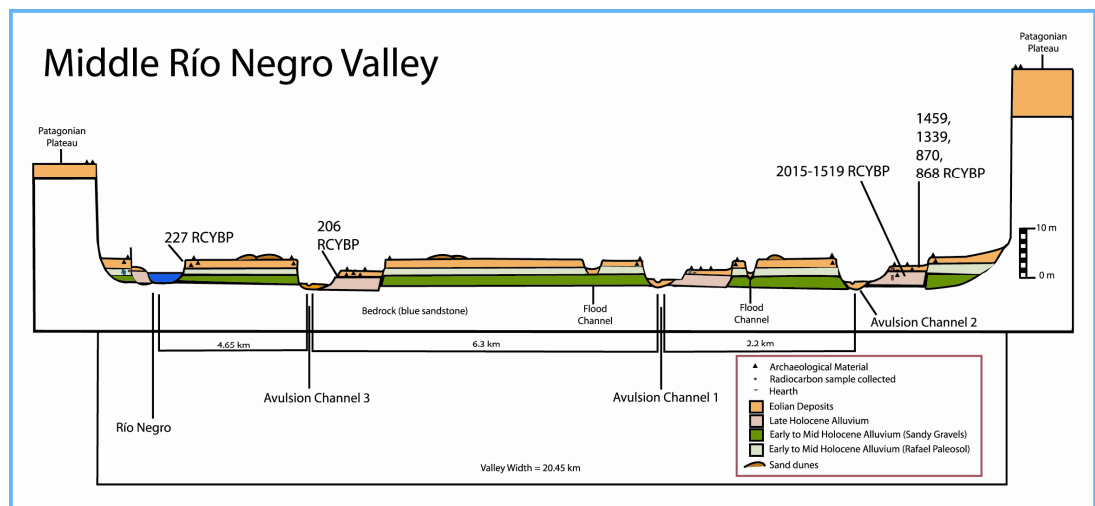
was possible to estimate the period that each channel served as the parent channel of the Río Negro. From radiocarbon dates of Avulsion Channel 2, avulsion may have occurred about 2500-2000 years  $^{14}\text{C}$  years BP. Based on the presence of archaeological materials buried in these alluvial sediments until 1500  $^{14}\text{C}$  years BP, this channel served as the



**Figure 35.** Profile of alluvium deposited by Paleochannel 3 at WP 356 (S39 56.365 W64 45.612).

main river channel until this period before the channel avulsed 8.5 km to the south to form Avulsion Channel 3. It is possible to suggest that this date could be pushed forward even further by the presence of archaeological sites found on the surface of these alluvial deposits although they are buried by eolian sediments. These sites date to 1460-1240  $^{14}\text{C}$  years BP and are found at the base of the overlying eolian deposits. Next, there appears to be a gap between these sites and archaeological sites found in shallower levels of the same eolian deposits. Two sites in this stratigraphic position were found along Avulsion Channel 2 and dated very closely to ca. 870  $^{14}\text{C}$  years BP. This suggests a gap in human occupation roughly between 1240-870  $^{14}\text{C}$  years BP (nearly 400 years). Reasons for this gap in occupation are discussed below. Using Avulsion Channel 2 as a chronological benchmark for this area of the valley, it is

possible to suggest that Avulsion Channel 1 was occupied by the Río Negro prior to 2500-2000  $^{14}\text{C}$  years BP before it shifted 2 km northeast to Avulsion Channel 2. In addition, Avulsion Channel 3 was possibly occupied by river waters after ca. 870  $^{14}\text{C}$  years BP. Figure 36 is a generalized cross section of the middle valley and represents the stratigraphy of the three avulsion channels, the modern channel, and the chronology of the three avulsions. Although flooding data from the 20<sup>th</sup>-21<sup>st</sup> centuries and features of the modern landscape (e.g., flood channels) suggests that flooding would have been a trigger event for avulsions, the required conditions for reaching an avulsion threshold are not as clear.



**Figure 36.** Generalized stratigraphic cross section of the Middle Río Negro Valley.

### ***Geoarchaeology of the Avulsion Channels***

In addition, numerous stratified archaeological sites were found located along the banks of each avulsion channel; their stratigraphic context likely indicates that they were occupied during the period that each avulsion channel served as the main channel of the Río Negro prior to avulsion. Therefore, an understanding of the timing, preconditions, and cause of these avulsions is important to archaeological interpretations because these events influenced human settlement patterns in this region. This influence is particularly important in arid environments, such as this valley, where fresh water is not widely accessible since there are no tributaries along the valley length that feed into this river. Therefore, the principal source for freshwater is the main river channel of the Río Negro which serves as a virtual “magnet” or attractive force for plants, animals, and humans in arid environments (Huckleberry 2001).

### ***Pools of the Three Avulsion Channels***

One other feature to the landscape history appears to have had an impact on the archaeological record of this region, and that is the formation of pools within the dry avulsion channels following their abandonment. Along the length of each of the three avulsion channels, more than 60 pools filled with water were identified on aerial photographs and during fieldwork (Figure 37). Some of these pools contain water whereas others remain dry (Figure 38). Pools are most commonly located on the inner side or shoulder of meander curves within these avulsion channels. Their average surface area ranges between 10,000-25,000 m<sup>2</sup> and some pools filled the surface of the



**Figure 37.** Crescent-shaped pool located within a meander of Avulsion Channel 2 (flamingos in the foreground for scale).

empty meander and extended upstream and downstream in the shape of a crescent.

During fieldwork, 28 pools were investigated and recorded in detail. Eight pools were recorded in Avulsion Channel 1, 10 pools were recorded in Avulsion Channel 2, and 9 pools were recorded in Avulsion Channel 3 (Table 13 and Figure 39). Selection of pools for recording was determined by a number of factors, such as a desire to document an even spatial distribution along the length of each avulsion channel. In addition, in channels with pools that contained brackish water (e.g., avulsion channels 2 and 3), an effort was made to record pools without brackish water since the majority of pools throughout the region were freshwater. Pools with associated archaeological material were recorded as well as pools where no archaeological material was evident.



**Figure 38.** Dry pool inside Avulsion Channel 2.

Recording of these pools occurred during the summer (January-February 2005) when average rainfall was low. A majority of the pools recorded were dry (Figure 37) except for pool 296 in Avulsion Channel 2 and pools 459, 454, 397, 404, 402, 403, and 368 in Avulsion Channel 3. Although a majority of the wet pools contained freshwater, a few contained brackish water as evident from dried salt deposits (Figure 40) lying on the perimeter of receding pools 296, 404, and 402. Salt deposits were also seen around several of the dry pools (e.g., pools 439, 477, 476, and 475) and it is assumed that they were deposited by water that formerly occupied these pools.

All of the pools documented in Avulsion Channel 1 were dry at the time of recording. Only one pool with water in this avulsion channel was observed in the field,

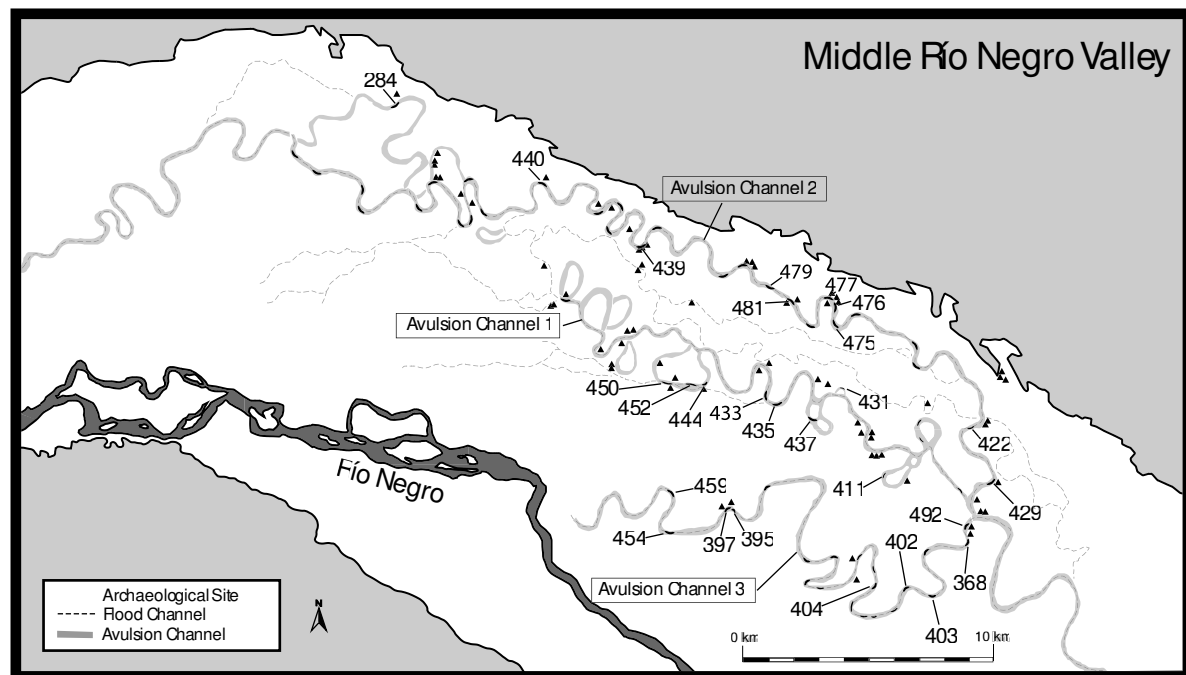


Table 13. Pools Recorded in Each Avulsion Channel.

	Pool	Location	Dry/Wet	Salt	Archaeology	Modern Fauna
Avulsion Channel 1	411	S39° 54.587' W64° 43.424'	Dry		No	No
	431	S39° 52.471' W64° 44.371'	Dry		No	No
	433	S39° 52.869' W64° 46.887'	Dry		No	No
	435	S39° 53.065' W64° 46.904'	Dry		No	No
	437	S39° 53.362' W64° 45.605'	Dry		Site 436	No
	444	S39° 52.538' W64° 48.513'	Dry		Site 344	No
	450	S39° 52.421' W64° 49.623'	Dry		Site 449	No
	452	S39° 52.509' W64° 49.289'	Dry		Sites 446, 447	No
	296	S39° 48.064' W64° 56.048'	Wet	Salt	Yes	No
Avulsion Channel 2	386	S39° 50.823' W64° 52.730'	Dry		Sites 172, 173	No
	422	S39° 53.364' W64° 40.625'	Dry		Sites 420, 421	No
	429	S39° 54.716' W64° 40.266'	Dry		Site 428	No
	439	S39° 49.623' W64° 50.437'	Dry	Salt	Site 240	No
	440	S39° 48.053' W64° 52.711'	Dry		No	No
	475	S39° 51.127' W64° 44.904'	Dry		Yes	No
	476	S39° 50.837' W64° 44.813'	Dry	Salt	Yes	No
	477	S39° 50.681' W64° 44.972'	Dry	Salt	Yes	No
	479	S39° 50.483' W64° 46.540'	Dry	Salt	No	No
	481	S39° 50.634' W64° 46.332'	Dry		No	No

Table 13 (Continued)

Avulsion Channel 3	Pool	Location	Dry/Wet	Salt	Archaeology	Modern Fauna
	368	S39° 56.230' W64° 41.234'	Wet		No	birds, coypo, ducks
	395	S39° 55.275' W64° 47.669'	Dry		Site 396	No
	397	S39° 55.296' W64° 47.844'	Wet		No	small fish, ducks
	402	S39° 57.096' W64° 42.881'	Wet	Salt	No	small fish, ducks
	403	S39° 57.244' W64° 42.007'	Wet		No	small fish, ducks
	404	S39° 57.596' W64° 43.511'	Wet	Salt	No	no small fish, ducks, geese
	454	S39° 55.836' W64° 49.324'	Wet		No	
	459	S39° 54.979' W64° 49.225'	Wet		Site 458	No
	492	S39° 56.049' W64° 41.337'	Dry		No	No



**Figure 39.** Location of pools recorded along the three avulsion channels.



**Figure 40.** The white material dried on surface sediments of pool perimeter is salt deposits.

indicating that wet ponds are not abundant in this channel any longer. None of the pools in Avulsion Channel 1 showed any evidence of brackish water or salt accumulation. The majority of pools in Avulsion Channel 2 were also dry at the time of recording, except for Pool 296 which contained brackish water as well. Four other pools also showed evidence that they once contained brackish water (pools 475, 476, 477). In Avulsion Channel 3, a majority of the pools recorded contained water except for pools 395 and 492.

### ***Pool Types***

The pools in all three avulsion channels were classified into two categories based on investigation of landscape features, flood channels, and stratigraphy. The wet pools

or stable pools maintain some capacity of water year-round. Pools which were dry during the time of recording were classified as ephemeral since even if they recently held water, it was not present throughout the year. Some of these pools may have been dry for long periods of time. However, some were replenished with water during large-scale flood events such as in 2001 where water was observed by local landowners in these avulsion channels distant from the modern river. Most of the pools which contain water were found in Avulsion Channel 3, and based on bank steepness and general estimation of pool depth the best explanation why these pools retain water even during dry periods is that they are likely cutting into the local water table. This would then supply these pools with a constant source of water. In addition, the level of the modern channel rises and falls during different seasons due to changes in discharge, and local landowners have also observed the rise and fall of the water level within these pools that correspond with changing levels in the modern river.

The ephemeral pools are mostly found in Avulsion Channels 1 and 2. Because these channels are older than Avulsion Channel 3, they have also undergone longer periods of eolian infilling within their channels. Therefore, many of these pools have infilled with eolian sediments and no longer cut into the water table as they once may have done although periodically they may temporarily fill with rainwater after intense storms. Flood channels are still evident in each avulsion channel and could potentially flow into any of these channels depending on the size of the flood.

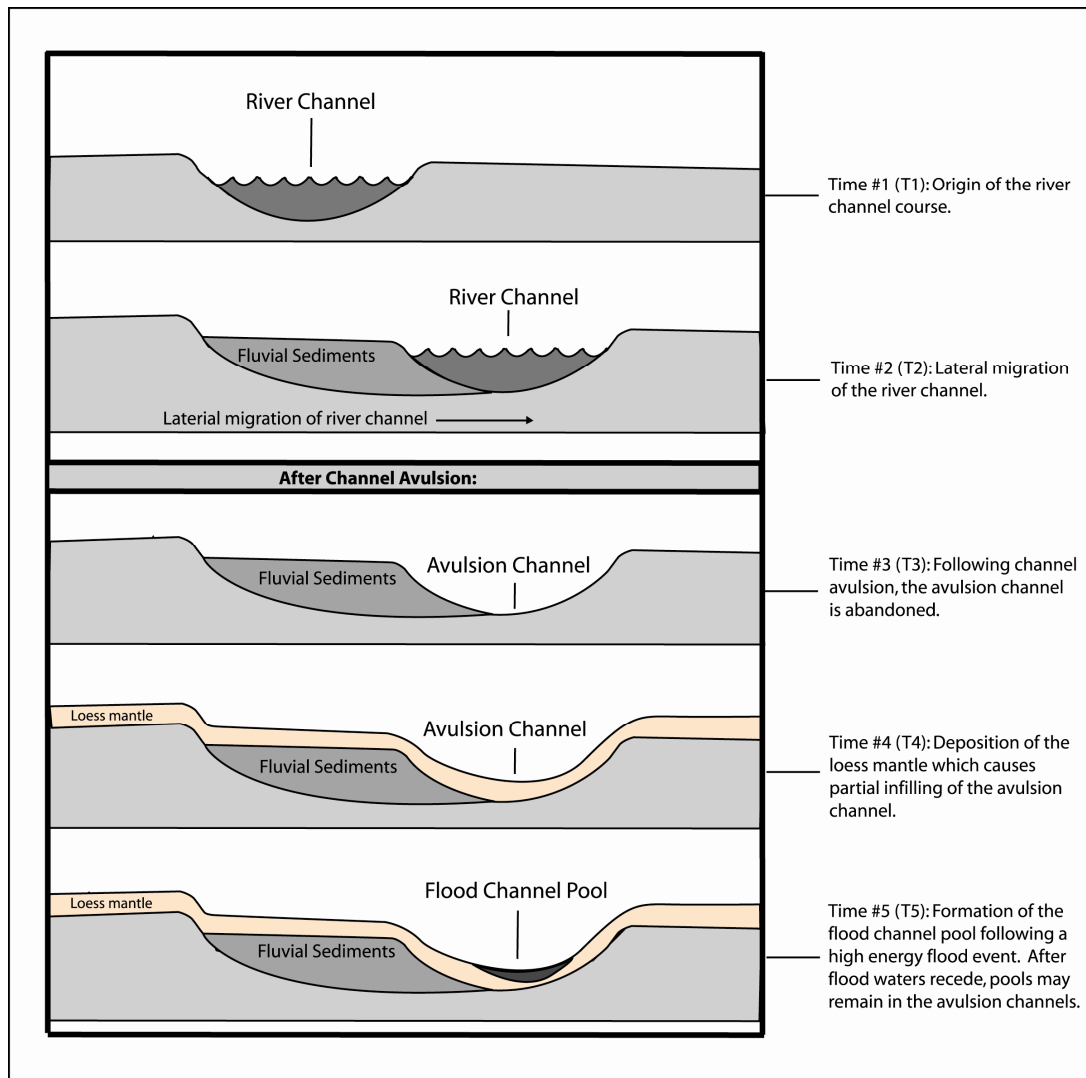
Another significant feature of these pools which was repeatedly observed in the field was that there would be a deposit of large gravels near the distal end (edge pointing

downstream) which graded and diminished in size downstream. In some cases when gravel deposits were not visible on the surface, deposits were also observed to be covered with eolian sediments deposited within the channel as observed along road cuts crossing the avulsion channels. Along some avulsion channel segments, it was possible to see a sequence of pool-graded gravel deposit-pool-graded gravel deposit.

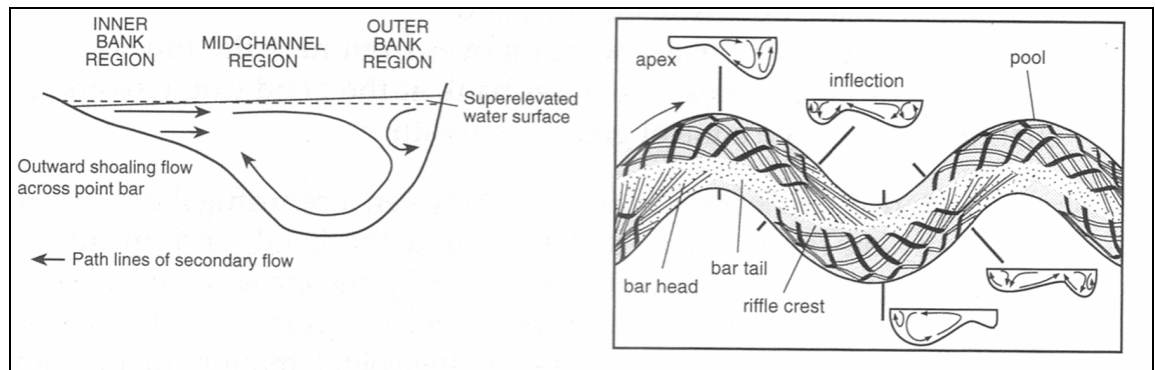
### ***Pool Formation***

From analysis of aerial photographs and field investigation, numerous small and dry flood channels exist throughout the study region. Some channels cut into an avulsion channel and follow its downstream course, whereas others cut across the regions between the avulsion channels. Within segments of each avulsion channel where pools were present, these pools consistently are found within the path of these flood channels. Sometimes consecutive pools can be seen connected by these channels. Therefore, it is most likely that the pools found within each avulsion channel were formed through erosional processes caused by these flood channels.

Based on field observations, the flood channels which flowed within the avulsion channels possibly cut into eolian fill which had accumulated within the avulsion channel over time (Figure 41). However, the flood channels cut into these infill deposits more deeply within the meander curve or apex, very similar to how a meandering channel erodes sediments along its course forming a sequence of pools and riffles (Figure 42). When the flooding recedes, what remains is a depression or “pool” within the meander apex that may remain filled with water for some period of time. This water may remain



**Figure 41.** Probable sequence of channel avulsion, loess infilling, and pool formation by flood channels.



**Figure 42.** General scheme of the formation of a meandering river channel which results in a pool-riffle sequence within the channel bed where the pools are located within the meander bend and the riffles are located between meander curves (after Knighton 1998, p. 218).

in this depression for a long period or even permanently should the depression cut deeply and intersect the water table.

As mentioned earlier, a graded deposit of rounded gravels was commonly found lying near the distal end of many pools (Figure 43). These gravels are likely fluvial in origin based on their rounded characteristics (Figure 44) and have been found comparable to gravels stratified within the avulsion channel bed as well as the gravels currently in the modern river. In addition, these deposits were clearly lying above the original riverbed on top of eolian infill and were not mistaken for *in situ* channel lag deposits. This analysis suggests that these gravel deposits were formed during the initial excavation of the meander pools when flood channels would have cut into the original avulsion channel lag deposits and deposited them downstream. High energy waters excavated gravels from these isolated areas and deposited them as water energy or transport

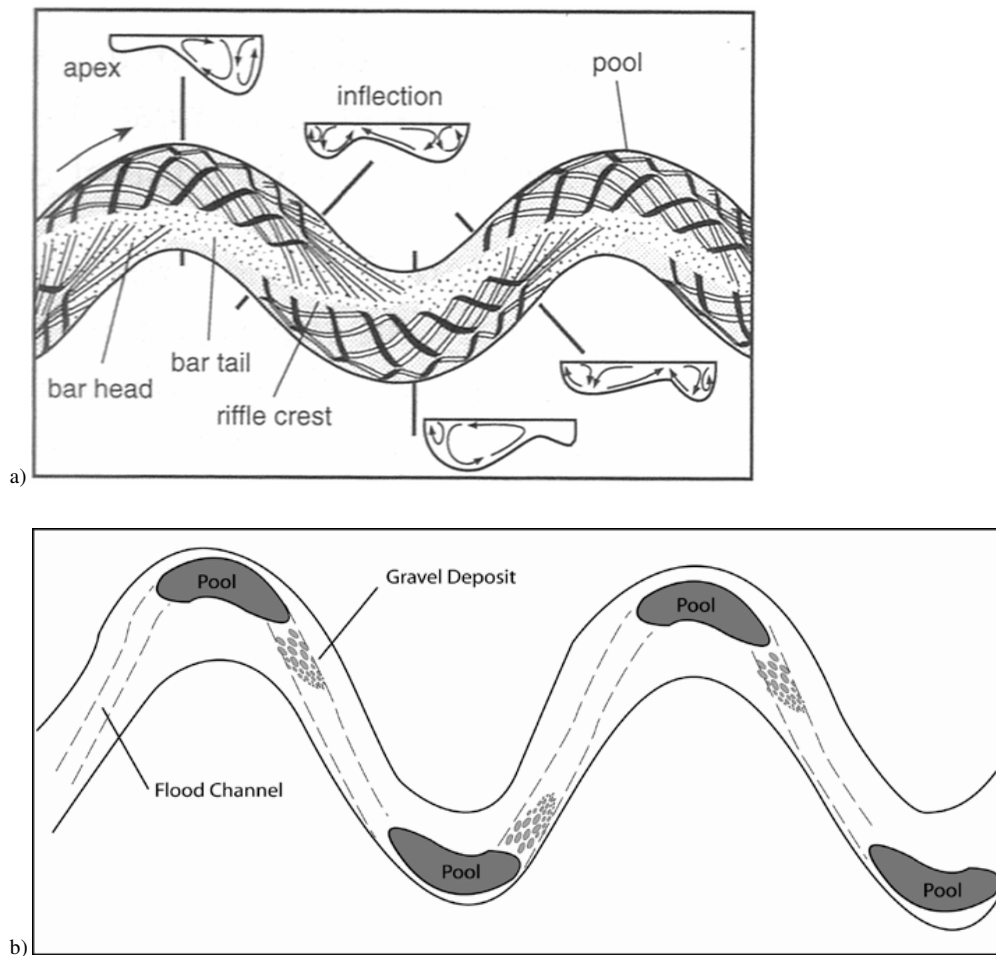




**Figure 43.** Graded gravel splay located near the distal end of a dry pool which formed in Avulsion Channel 1 (dry pool in background at light area).



**Figure 44.** Fluvial gravels found on the dry channel bed of Avulsion Channel 2 near the distal end of a dry pool.



**Figure 45.** a) Standard scheme for a pool-riffle sequence (after Knighton 1998, p. 218). and b) observed pattern of pool-gravel sequence in each avulsion channel where pools formed within meanders.

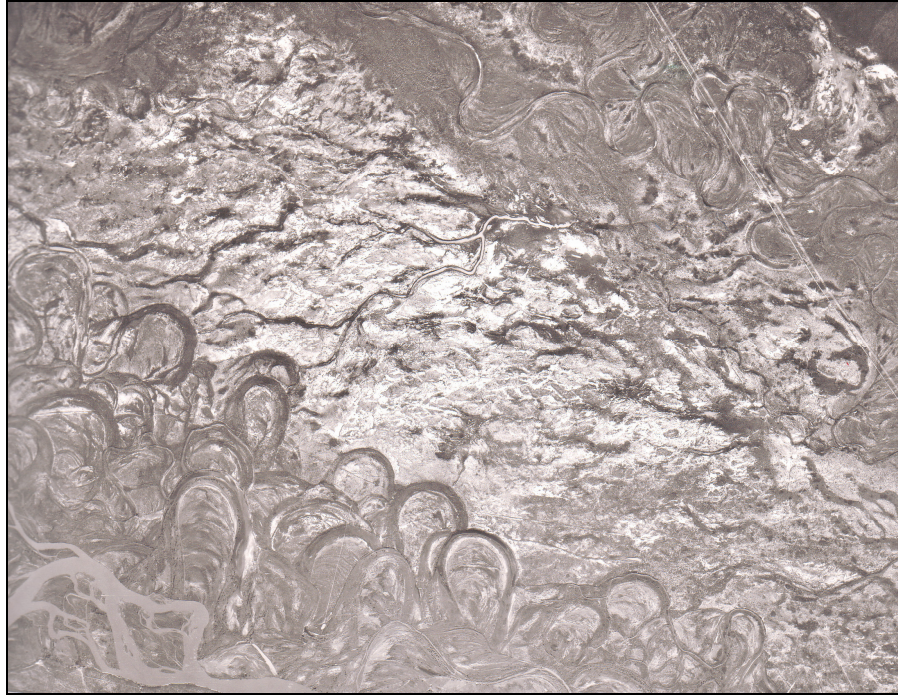
capacity dropped shortly beyond the distal end of the pool where the gravels were deposited. Although pools with distal gravel deposits can be found in isolation, frequently they are found as a chain sequence or pool-gravel deposit sequence (Figure 45). Again, this is a sequence similar to a pool-riffle sequence inherent to meandering

river channels. Therefore, these gravel deposits are the re-deposited channel lag gravels which originated from each avulsion channel. One explanation for this fluvial behavior could be the cohesive sediment content of the avulsion channel riverbanks which could have restrained the lateral movement of these flood channels, causing them to cut deeper into erodible channel sands and gravels rather than the clay-cohesive cut banks.

### ***Role of Flooding in Formation of Avulsion Channel Pools***

The most evident cause for the formation of the avulsion channel pools is flooding. The magnitude and frequency of floods are recorded in the valley geomorphology and from historical accounts. Flood channels not only incise existing channels but frequently cut across valley fill (Figure 46). These channels are also easily recognizable in the field because they lack overbank deposits and evidence for lateral migration as with the avulsion channels. They are also smaller in size. As discussed in Chapter II, modern flood history has recorded numerous large-scale and catastrophic flood events in the Río Negro Valley since 1779. As a result of the devastating floods which occurred in 1899 and 1900, efforts were undertaken to regulate the Río Negro in order to prevent or mediate such flooding. A number of dams were constructed in the upper valley on the Río Limay and Río Neuquén and although flooding does occur periodically in the valley (e.g., 2001), regulation has significantly diminished their magnitude and impact. Based on the presence of numerous flood channels and the modern flood history of the Río Negro, this suggests that post-abandonment avulsion channel pools formed as a result of

flood events. Not all flood events likely formed or occupied flood channels across the valley. It is likely that the largest-scale floods breached the river banks to a degree



**Figure 46.** Flood channel (center) cutting across Early to Middle Holocene alluvium from old meanders of the modern river (lower left corner) to avulsion channel 1. Note flood channel following course of avulsion channel 2 (upper right corner).

significant enough to spill over onto adjacent plains, funneling water which eventually gathered to carve out flood channels. These channels reached across existing deposits and eventually cut into the course of avulsion channels.

### ***Summary***

The Río Negro Valley formed in the Middle Pleistocene as the result of tectonic uplift which caused the proto Río Negro to downcut the Río Negro formation. This large braided regime created two gravel terraces during the Late Pleistocene. A shift in the fluvial regime occurred in the Late Pleistocene or Early Holocene. Although the river diminished from its former Late Pleistocene size, it remained a braided regime depositing fine gravels mixed with coarse sand. On preserved remnants of the fine sand unit deposited over this gravel unit, the Rafael paleosol formed. During the Middle Holocene or Early Late Holocene, the Río Negro shifted to a meandering-anastomosing regime which periodically experienced channel avulsions. Eolian sediments from each time period are preserved throughout the valley and generally cap alluvial terraces, predominantly in the form of loess and in some cases dune deposits. During the Late Holocene, three channel avulsions and abandoned avulsion channels were reoccupied during large-scale flood events. Within the channels, a chain of pools formed along the length of each avulsion channel within channel meanders most likely by flood events. In many cases, water remained in these pools after floodwaters receded. The next chapter considers the possible impacts that these events have had on the behavior of humans in the Middle Río Negro Valley, and how these impacts are reflected in the archaeological record.

**CHAPTER V**

**CONNECTING THE LANDSCAPE HISTORY WITH THE**

**ARCHAEOLOGICAL RECORD:**

**PRESERVATION OF THE ARCHAEOLOGICAL RECORD AND THE IMPACT**

**OF LATE HOLOCENE LANDSCAPE PROCESSES ON SETTLEMENT**

**PATTERNS**

**Introduction**

The archaeological record is not independent from landscape history in any region. In fact, it is quite dependent on the landscape and its processes for its survival and preservation. A major benefit of regional geoarchaeological investigation is the reconstruction of landscape history. Such reconstructions divide up the landscape by defining its individual components (i.e., landforms and deposits) which compose a landscape and organize the landscape by placing these components into a relative chronological order in which they were deposited. Then, it is possible to determine which terrestrial deposits remain preserved and which are absent, their relative and absolute ages through dating, and their potential for containing preserved and intact archaeological sites through analysis of the depositional and post-depositional processes which affected each deposit.

The landscape reconstruction of the Middle Río Negro Valley was discussed in the previous chapter. In this chapter, the potential preservation of the archaeological record within the landscape and the impact of landscape history on past human behavior



are discussed for the Late Pleistocene through Late Holocene. Although landscape can have a significant impact on where humans settle and subsist, it is necessary to emphasize that ultimately, it is humans who select site locations and subsistence strategies. It is not suggested that this reasoning is solely dependent on the status of their surrounding environment. These thought processes are considered independent factors that influence human settlement patterns.

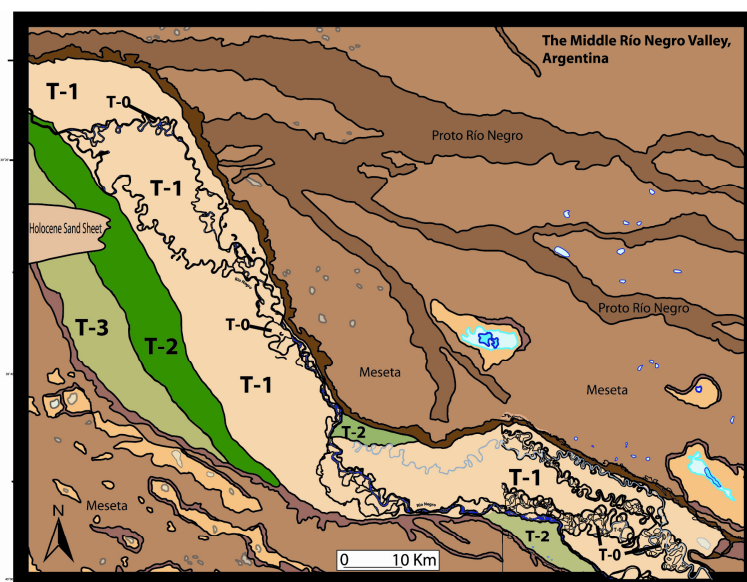
### **Preservation of the Archaeological Record**

All modern landscapes are incomplete. That is to say, partial or complete deposits or landforms previously deposited are missing due to a variety of erosional processes which remove portions of landforms at any point in time. For example, a major portion of a deposit or landform from a particular period could be missing due to erosional processes which focus on that particular area of the landscape. The same is true for the archaeological record which is contained within these deposits.

As mentioned above, through landscape reconstruction and dating of its individual components, it is possible to determine which deposits and archaeological sites still remain in a landscape and which have been eroded away and are no longer preserved. For example, in some areas, archaeological sites and natural deposits from the Late Holocene are well-preserved and more abundant than other periods. This is not due to their younger age, but related to the fact that much of the earlier deposits have been scoured away in this part of the valley. In another region of the valley, it is likely that sites from the Early to Late Holocene are equally well-preserved and represented

where the landforms or deposits from each period are also equally represented and preserved. The amount of site preservation signifies the representation of the archaeological record. This type of information is crucial for evaluating the archaeological record and making conclusions about past human behavior and settlement patterns within a given region. If not, there is a risk that interpretations of human behavior may actually be the result of a bias or skewness in the representation of the archaeological record caused by the differential preservation of the landscape.

Figure 47 represents the deposits remaining within the Middle Río Negro Valley from the Late Pleistocene (alluvial terraces  $T_3$  and  $T_2$ ), Early to Mid Holocene ( $T_1$ ), and Late Holocene ( $T_0$ ). Nearly all alluvial deposits in this valley are covered by a

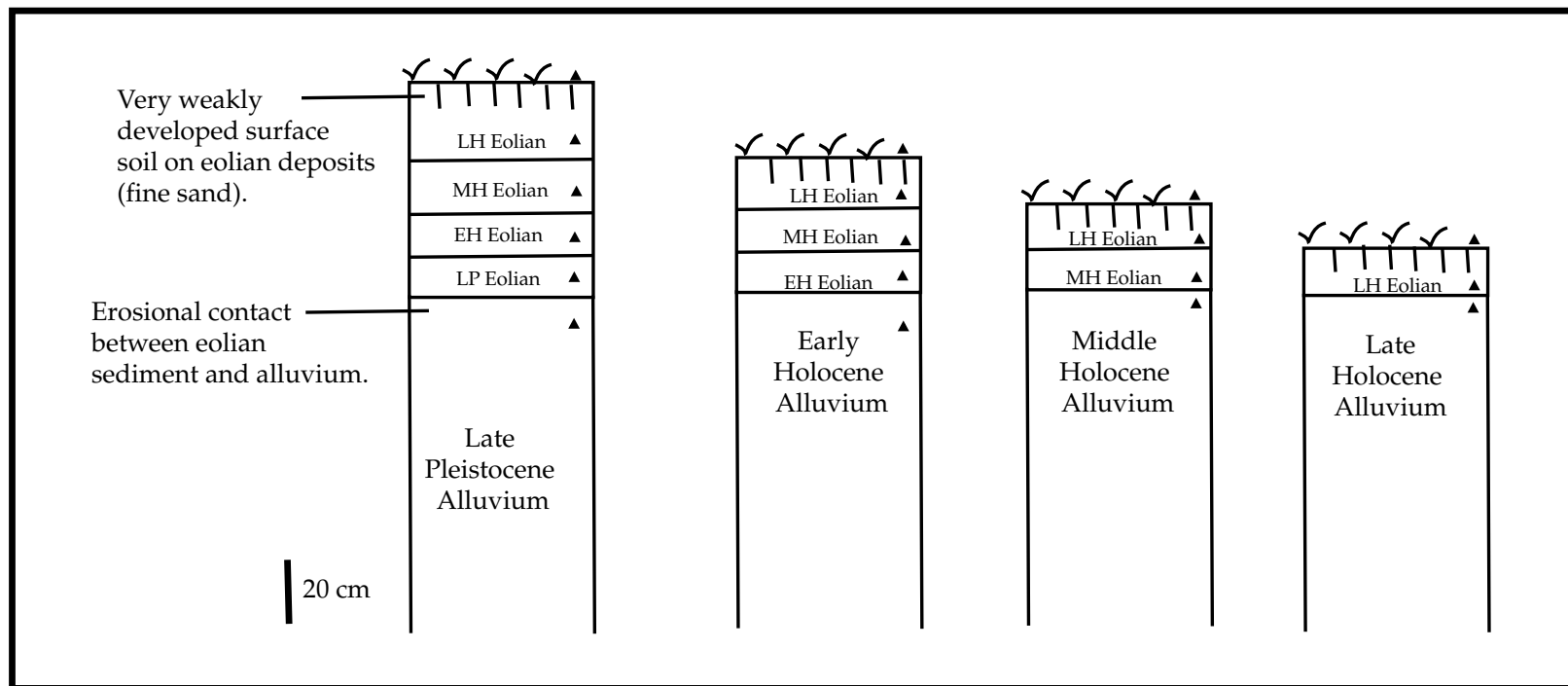


**Figure 47.** Geomorphic map of the Middle Río Negro Valley.



mantle of eolian sediments (i.e., loess) which has not yet been dated although stratigraphically it post-dates its underlying alluvial deposits. OSL samples are currently being processed and will help clarify the chronology of these eolian deposits. Within the middle valley as illustrated in Figure 47, a little more than 30% of the area within the valley margins consists of Late Pleistocene alluvium ( $T_2$  and  $T_3$ ), nearly 55% of alluvium is the Early to Middle Holocene thick gravel alluvium ( $T_1$ ), and the remaining Late Holocene deposits ( $T_0$ ) consist of approximately 15% of the alluvium in the Middle Rio Negro Valley.

In summary, within the middle Río Negro Valley the Early to Middle Holocene alluvial deposits are the most abundant (55%), the Late Pleistocene alluvial sediments are also well-represented (30%), and the Late Holocene are the least abundant (15%). However, there is another important element of the landscape that must be included although it complicates the evaluation of landscape and archaeological preservation. As mentioned above, each alluvial deposit is covered by eolian deposits and deposition of the eolian sediments began shortly after the alluvial sediments were deposited and continued on until the present. Therefore each of these alluvial deposits from the Late Pleistocene through Late Holocene is buried under a series of eolian deposits which potentially date from the time of alluvial deposition until the present. For example, Late Pleistocene alluvial terraces are buried by eolian sediments that may date from the Late Pleistocene to the Late Holocene, Early Holocene alluvial deposits are buried by Early to Late Holocene eolian sediments, Middle Holocene alluvial sediments are buried by eolian sediments from the Middle to Late Holocene, and Late Holocene alluvial are



**Figure 48.** Sequence of eolian deposits overlying alluvium in the Middle Río Negro Valley from the Late Pleistocene (LP), Early Holocene (EH), Middle Holocene (MH), and Late Holocene (LH). Archaeological sites may potentially be found in any of these strata (black triangles).

buried by Late Holocene eolian sediments (Figure 48). The corresponding deposits could potentially contain archaeological material from each of these periods as well. This theoretical model must be qualified by the possibility that erosion could potentially erode away any of these deposits through time in any location. The result is a fragmentary and biased geological and archaeological record from which archaeological evaluations of past human behavior and settlement patterns should be based. Furthermore, if the Río Negro Valley had been consistently populated by similar densities of human populations throughout time and these occupations were evenly distributed through the valley, then our study of human behavior and settlement patterns would be straightforward. However, this is never the case and fluctuations in settlement density, archaeological site distribution, and differential preservation of the landscape and archaeological record must be taken into consideration when evaluating past settlement patterns.

All of the archaeological sites recorded by this project and by the project directed by Prates date to the Late Holocene based on radiocarbon ages and artifact technology. Although we are beginning to establish the cultural chronology for the Middle Río Negro Valley, it has been poorly defined up until now since little archaeological investigation has been conducted in this region. However, ceramics and small arrow points (i.e., used with a bow and arrow) were found at many of these Late Holocene archaeological sites and neither technology was introduced into the Pampas until ca. 3000 BP (Politis, et al. 2001). Therefore, potential preservation of sites from the Late Holocene is very high even though Late Holocene alluvial deposits have the lowest

representation in the Middle Río Negro Valley. In addition, Late Holocene eolian deposits are present in nearly 100% of the valley. Therefore, the landscape history of the Middle Río Negro Valley, as in most regions, creates a strong bias when site representation is not evaluated using by the degree of landscape representation for a particular period. This point is very important when comparing cultures of one region to adjacent areas.

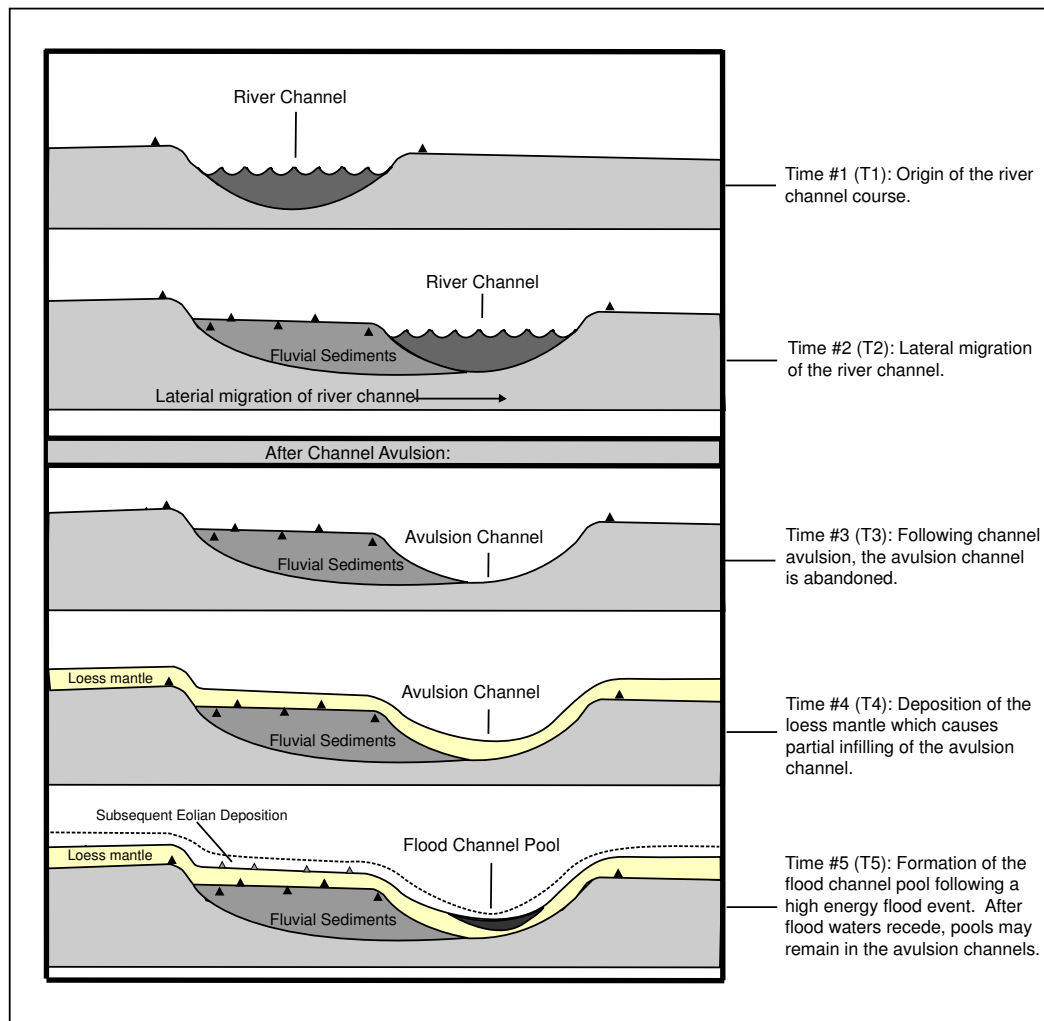
The greatest potential for finding archaeological material will be in alluvial deposits and secondly in eolian deposits. Sites occupied along the riverbanks and floodplain of the Río Negro would have been well-preserved by factors such as overbank floodwaters. For sites that reoccupied abandoned avulsion channels, these sites would also be well-preserved by eolian deposition. However, caution should be used when considering the formation of palimpsests due to erosion and bioturbation, and such factors were taken into consideration.

### **Potential Impact of Channel Avulsion and Pond Formation on Late Holocene Settlement Patterns**

Landscape reconstruction can not only determine which natural deposits are present but also which archaeological sites are present and evaluate the preservation of the archaeological record. In addition, it can also make important insights into how changes in a landscape could potentially influence human settlement patterns. In the Middle Río Negro Valley, two types of events likely had an influence on human

settlement patterns during the Late Holocene: channel avulsion and subsequent pool formation within abandoned avulsion channels.

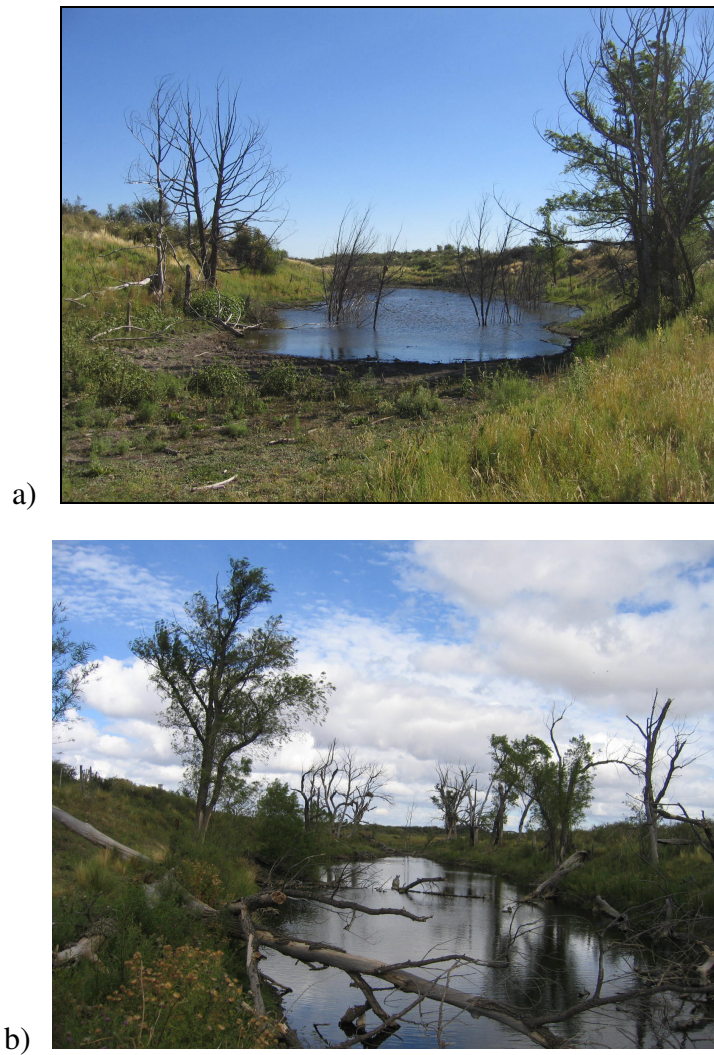
As discussed in Chapter IV, during the Late Holocene, the Río Negro abruptly avulsed three times shifting its course several kilometers each time. For each of these new river courses, human occupation shifted to each channel when it served as the principal channel of the Río Negro. These sites were located within or on the surface of alluvial sediments (i.e., floodplain and overbank sediments) adjacent to each channel and buried by the overlying eolian mantle (Figure 49, A, B, C, and D). Due to the depositional environment, these sites would likely be intact sites in primary context unless disturbed by subsequent eolian erosion or bioturbation. However, according to the stratigraphy of these sites, it appears that these channels were occupied during two different periods: 1) when a channel was the principal channel of the Río Negro (Figure 49 A) and 2) around pools which formed within channels subsequent to abandonment (Figure 49, E). Sites occupied which are contemporary with the abandoned channel pools were located on the surface of eolian sediments which were overlying the alluvial sediments previously deposited by the channel (Figure 49 E). Once abandoned, these sites were buried by additional eolian sediments (dashed line in Figure 49 E). These sites would also be intact archaeological sites if they are rapidly buried by eolian sediments and were not re-exposed by wind erosion. Since wind erosion is fairly common, sites located in “blowout zones” or re-exposed should be studied with caution. Otherwise, these sites buried in the fine eolian mantle appear well-preserved. Therefore, each channel potentially underwent two stages of occupation, during the pre-avulsion



**Figure 49.** Potential locations for buried archaeological sites (black and gray triangles). Gray triangles signify sites occupied after pool formation in abandoned avulsion channels.

(principal channel phase) and post-avulsion (pool phase). The second stage of occupation for each avulsion channel occurred during the period after a channel was abandoned and potentially until the European Contact period. Initially, it was not clear in the field why these channels were reoccupied once they were abandoned. However,

after further field investigation, there were two patterns evident in the landscape and archaeological record which seemed to correspond to each other and offer an explanation as to why the avulsion channels were reoccupied. The first pattern was the increase in density of archaeological sites along certain segments of each avulsion channel which according to the stratigraphy (i.e. burial in the upper units of the eolian mantle) were occupied post-avulsion. Visibility was taken into consideration and after evaluation, it was determined that visibility along the length of each channel is generally constant so that this increase in sites was not a factor of increased visibility. The second pattern noted within the avulsion channels on aerial photographs and in the field was the presence of pools within meander curves at fairly regular intervals along their channel length. Finally, these two patterns appeared to correspond to each other and archaeological sites were predictably found associated with the pools that formed within the channels (Figure 50). Therefore, when taking into account the resources that these pools could offer a small population of Late Holocene foragers (i.e., fresh water, water fauna, birds, river cobbles for lithics), it appears that these abandoned avulsion channels could have been reoccupied because of the pools that formed within the channel meanders. The “pool” sites were likely temporary campsites that were used to procure raw materials for lithics and used as hunting stations before returning to the more established sites along the main river. At several sites, it was evident that river cobbles abandoned in the avulsion channel had been carried up into the riverbank. These small workshop sites were likely occupied for short periods of time since the resources offered



**Figure 50.** Wet pools (a) and (b) recorded in January 2005.

in this location would have been of lower abundance and diversity than those provided by the main river channel.

This second pattern of occupation of sites around these pools, was not detected until the last part of the first field season in January 2005. At this point, it was not possible to systematically survey the length of each avulsion channel to record all pools and archaeological sites associated with or without the pools in order to construct a



quantitative database. However, repeated observations of the stratigraphy, geomorphology, and archaeology across the region suggested that such a pattern is a strong possibility. It would be a productive investigation to conduct such a systematic survey in the future and may be the continuation of this project during a future field season.

## **CHAPTER VI**

### **CONCLUSIONS**

This study resulted in two sets of conclusions regarding the landscape history of the Río Negro Valley and how this landscape history had an impact on the archaeology of the valley in terms of site preservation and human settlement patterns.

The landscape history includes the following sequence of events regarding the valley origin, valley deposits, fluvial regimes through time, and post-abandonment activity in avulsion channels:

- Around the Middle Pleistocene, the Río Negro Valley formed as the result of tectonic uplift which caused initiation of the proto-Río Negro and beginning of valley incision.
- During the Late Pleistocene, the Río Negro was a large braided stream and deposited two gravel terraces ( $T_3$  and  $T_2$ ) and two paleosols formed on each terrace (Pleistocene Paleosols 1 on  $T_3$  and Pleistocene Paleosols 2 on  $T_2$ ).
- The second Pleistocene terrace ( $T_2$ ) was downcut during the Late Pleistocene or Early Holocene.
- From the Early through Middle Holocene, a gravel terrace of fine gravels and coarse sand covered by a fine alluvial sand ( $T_1$ ) was deposited by the Río Negro. This river was a braided stream although smaller in scale compared to the Late Pleistocene river.

- During this period, the Rafael paleosol formed on this fine alluvial sand deposit (chronology is pending due to OSL samples in process).
- In the Middle Holocene or Early Late Holocene, the Río Negro shifted from a braided regime to a meandering-anastomosing regime which periodically underwent channel avulsions.
- During the Late Holocene, there were 3 channel avulsions in the Middle Río Negro Valley; Avulsion Channel 1 was occupied before 2500-2000 BP, Avulsion Channel 2 was occupied from 2500/2000 BP until ca. 1200 BP, and Avulsion Channel 3 was occupied from ca. 1200 BP until ca. 200 BP.
- 30% of the remaining valley alluvium of the Middle Río Negro valley was deposited during the Late Pleistocene (moderately abundant)
- 55% of this alluvium is the Early to Middle Holocene alluvial fine gravel-coarse sand (most abundant)
- 15% of the alluvial sediments were deposited during the Late Holocene (least abundant)
- The valley was continually affected by flooding and therefore flood channels are common throughout the valley.
- Flood channels within abandoned avulsion channels are responsible for the formation of pools which formed along the length of each abandoned avulsion channel.

The second set of conclusions concerns both the preservation of the archaeological record and how changes in the landscape history had an effect on human behavior during occupation in the Middle Río Negro Valley.

- All archaeological sites detected by surface survey (conducted by Prates) and geoarchaeological fieldwork (>200) are from the Late Holocene, indicating that the potential preservation of Late Holocene sites is excellent.
- Preservation of the archaeological record, including datable material, for the Late Pleistocene through Middle Holocene is good but most sites from this period are deeply buried in alluvial terraces and in the eolian mantle.
- Preservation of archaeological materials from the Late Holocene is very good and sites should also be found in alluvial and eolian deposits.
- During the Late Holocene, each avulsion channel in the Middle Río Negro valley was occupied on 2 occasions: 1) which each channel served as the principal river channel (pre-avulsion) and 2) around the pools or “oases” which formed within each avulsion channel (post-avulsion).

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